Chapter 17
Exploring the Relationships Among Prior Knowledge, Perceptions of Climate Change, Conceptual Understanding, and Scientific Explanation of Global Warming

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Abstract Topics of global warming and climate change involve complex and controversial problems that current society faces globally and locally. Equipping citizens with sufficient understanding, positive attitudes, and the ability to participate in discussions of critical issues are important aims of climate change education. To reach these goals, a digital module was developed which utilizes a conceptual change approach to address learners' fragmented concepts and misconceptions. Pedagogical approaches including persuasive texts and critical evaluation were additionally incorporated to help learners construct explanations of global warming and to promote positive perception shifts. Influence of the module on conceptual understanding and perception shifts was explored. The interplay between knowledge and perceptions of climate change as well as the influence of scientific explanation on cognitive and affective outcomes were further investigated using partial least squares structural equation modeling. The results provide insights into how to support learners to develop understanding, enhance the quality of their science explanations, and promote perception change regarding global warming.

Keywords Attitude · Climate change · Knowledge · PLS-SEM · Scientific explanation

17.1 Introduction

There is a growing consensus that climate change is happening and it is mainly driven by emissions of greenhouse gases from human activities. The UN Framework Convention on Climate Change (United Nations, 1992), the Paris Agreement (United Nations, 2015), and the Special Report: Global Warming of 1.5°C released by the

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Intergovernmental Panel on Climate Change (IPCC, 2018) stress the importance of education to empower individuals with knowledge, attitudes, and skills to act as agents of change. Educating literate citizens about climate change is critical to ensure that they are able to make adequate decisions when participating in related discussions. Promoting climate change education is urgent, and increasing effort has been devoted to developing courses and instructional modules in K-12 and formal higher education settings. Yet, most current adult citizens who actively participate in civil decisions have left the formal education settings. Therefore, developing self-directed online modules accessible on the Internet is a promising way to take opportunities of learning beyond the formal educational institutions to learners.

Raising public understanding and awareness of climate change is an important but challenging task. One of the challenges lies in the conceptual difficulties due to the multidimensional nature of the issue and the embedded concepts, such as the greenhouse effect and the carbon cycle that are often abstract, intangible, and require thinking and reasoning at the system level to understand their interactive nature (Sinatra et al., 2012). Possessing limited knowledge, misconceptions, or fragmental mental models may hinder individuals from gaining awareness of themselves as causal agents within climate problems, and may prevent them from making literate decisions (Tasquier & Pongiglione, 2017).

Another challenge concerns individuals' competency in synthesizing reasonable explanations or evaluating the quality of arguments about climate issues. Active participation in discussions and decision-making about climate issues requires individuals who accurately and adequately understand, interpret, and evaluate the quality of claims, evidence, and scientific inquiry processes presented in the news or media reports (Sherin et al., 2012). Individuals who lack this competency often hold biased beliefs or make decisions based on biased viewpoints without being aware of them. Unfortunately, many individuals do not understand what counts as or the purpose of scientific explanations (Lombardi et al., 2013; McNeill et al., 2006), or they lack experience of evaluating arguments and explanations (Wang, 2015). Lacking adequate scientific understanding may also hinder individuals from making judgments about the appropriateness of evidence or of the warrants involved in the arguments (Sampson et al., 2011).

Although abundant efforts have been made to enhance conceptual understanding (e.g., Versprille et al., 2017), to promote attitude change (e.g., Sinatra et al., 2012), or to foster critical evaluation of the evidence-argument connections (e.g., Lombardi et al., 2013, 2016), previous efforts have addressed barriers of climate change education in a separate manner. Equipping students with the competency to scientifically explain the climate change phenomenon is tightly related to raising system understanding and shifting attitudes. Yet, gaps remain that require more efforts to identify pedagogical approaches for developing integrated and effective instruction. First, meaningful understanding of global warming requires individuals to construct a holistic mental representation to conceptualize and reason causal relations of the phenomenon (Harris & Gold, 2018; Libarkin et al., 2015). While approaches have been developed to enhance individuals' climate change knowledge, an effective approach that addresses resistant misconceptions while building a more holistic, inner consistent mental model of climate change is rarely seen. Secondly, raising conceptual understanding can serve as a knowledge base for developing competency of scientific explanation when engaging learners in scientific discourses; this explanative instruction may potentially influence individuals' perceptions of the related issues. Yet, the influence and relations of conceptual understanding and scientific explanation with individuals' perception change are not inclusive and require more supporting evidence.

This study, therefore, aimed to address these gaps through carefully planning and integrating pedagogical approaches to jointly foster system understanding, adequate scientific explanation, and a positive attitude toward climate change. A conceptual change approach was applied to address the aforementioned conceptual barriers to understanding climate change. A scientific explanation unit then follows to provide opportunities to engage learners in scientific reasoning discourses through refutation texts and critical evaluation. In addition to evaluating the influence and effectiveness of the integrated pedagogical approaches, a further step is taken to explore the interplay between the cognitive (e.g., prior knowledge) and affective components (e.g., beliefs or perceptions), as well as related factors (e.g., scientific explanation ability), using partial least squares structural equation modeling (PLS-SEM). Specifically, the following questions were proposed:

1. How does the climate change digital module influence adult learners' content knowledge of and change in attitude toward climate change?
2. What patterns of interrelationships among the knowledge about, attitude toward, and quality of scientific explanation of climate change can be found prior to and after experiencing the digital module?

In the following sections, previous literature is first explored to identify the conceptual barriers to be addressed, essential components to be included, and effective pedagogies to design a digital learning module on climate change. Next, established literature is summarized to form my hypotheses regarding whether and to what extent enhancing conceptual understanding and promoting competency of scientific explanation of climate change may change attitudes.

17.2 Literature Review

17.2.1 Conquering Cognitive Barriers to Climate Change

17.2.1.1 Addressing Learners' Concept Deficiency and Misconceptions

Conceptual construction and conceptual change require that newly introduced concepts be plausible and readily assimilated into the schema learners currently hold (Posner et al., 1982). She (2004) argued that the hierarchical level of a concept also influences the relative ease or difficulty when learners experience conceptual conflict and reconstruction. Learning a concept at a higher hierarchical level requires more underlying concepts for successful conceptual change (She, 2002). If learners' misconceptions and lack of mental sets are identified, and corresponding learning events are carefully chosen to create dissonance (conceptual conflict between current experience and previous understanding) in the cognitive process, radical conceptual change may take place within a short period of intervention (She, 2004).

Climate change involves understanding the underlying array of concepts, complex processes, and causal relations, and requires learners to link several systems into a functional mental model (Aksit et al., 2018). Thus, climate change is classified as a higher-level concept in the hierarchy, and requires adoption of the Dual-Situated Learning Model (DSLM; She, 2004) to plan and structure the content and learning activities of the instructional module. The DSLM suggests that instructors examine attributes of the science concept to identify the essential mental sets, such as basic concepts or procedures, needed for holistic understanding. Learners' misconceptions are then analyzed and compared to the list of required mental sets to pinpoint the mental sets needed for designing learning events.

To address concept deficiency and misconceptions related to climate change, a unit targeting conceptual understanding was developed by following the procedure suggested by the DSLM. A review of the related literature was summarized to identify essential components to be included in a scientific view of global warming and is listed in Table 17.1. Some major confusions or misconceptions which need

Table 17.1 Mental sets (boldface print) and their subsumed topics in the global warming unit

1. What is the greenhouse effect
1.1 The energy balance of the Earth
1.2 The mechanism of the greenhouse effect
1.3 The characteristics of the electromagnetic spectrum and the differences between the incoming Sun's radiation and the Earth's re-radiation that interacts with greenhouse gases
2. Factors affecting the greenhouse effect
2.1 The amount of greenhouse gases in the atmosphere
2.2 The amount of the Sun's radiation being absorbed or reflected by the Earth's surface
2.3 Opportunities to apply the newly acquired mental sets to a new situation to ensure successful construction of the mental model
3. Characteristics of greenhouse gases: Characteristics that differentiate greenhouse gases (e.g., carbon dioxide, water vapor, methane, CFCs, or nitrous oxide) from non-greenhouse gases
4. Comparing global warming potential of different greenhouse gases and using the bathtub analogy to explain why global warming will persist for centuries
4.1 Sources, amount, propositions of different greenhouse gases emitted
4.2 The atmospheric lifetime of different greenhouse gases
4.3 The changes of carbon dioxide concentration in the atmosphere
Additional mental sets not addressed in this module:
5. Differentiating the natural greenhouse effect from the anthropogenic effect
6. Actions to mitigate the effects of climate change

to be addressed were identified, including individuals not differentiating between shortwave radiation coming in from the Sun, and longwave radiation emitted by the Earth (Harris & Gold, 2018). Many individuals do not understand the role that greenhouse gases play in regulating the Earth's energy balance, nor are they able to articulate characteristics that distinguish greenhouse gases and non-greenhouse gases (Versprille et al., 2017). Some learners possess an incorrect mental model involving ozone depletion (Harris & Gold, 2018; Libarkin et al., 2015). A series of conceptual change learning events was then developed accordingly to challenge the learners' existing concepts and to provide new mental sets accordingly.

The mental sets and subsumed topics were used to design the learning events that involved carefully selected and planned explanatory texts with charts or graphs, animations, analogies, or discrepant events corresponding with the targeted ideas. Throughout the unit, self-explanation prompts, sequencing tasks, prediction-observation-explanation (POE) events, or matching tasks were carefully embedded in the learning events as seamless formative assessments to cognitively engage the individuals.

17.2.1.2 Fostering Competency of Scientific Explanations

Educators need to target both cognitive and affective outcomes to foster citizens with adequate knowledge and positive attitudes as active decision makers about the climate emergency. Merely raising understanding of the climate change phenomena, however, will not necessarily lead to changes in individuals' perceptions or beliefs about the issues and consequences. Engaging learners in additional activities to critically evaluate climate change explanations on different stances (e.g., Lombardi et al., 2013) or to reason with scientific discourses in persuasive texts (e.g., Sinatra et al., 2012) has shown to be promising in promoting deeper understanding or attitude change.

Several efforts have been made to develop pedagogies or supports to promote competency of scientific explanations. For example, providing learners with cues that link a specific type of knowledge to a claim or supplementing a context-situated, refined standard to evaluate explanations, were effective in terms of improving the quality of scientific explanation (Wang, 2015). Other effective supports include: explaining the epistemic criteria of knowledge (Duschl, 2008), or weighting the appropriateness and the strengths in the connection between the evidence and the arguments using a visualization tool (Lombardi et al., 2013). Engaging learners in evaluating arguments on both sides of the issue may further reduce 'myside bias' (Yen & Wu, 2017).

To develop the scientific explanation unit, the aforementioned features were considered during my design. The unit begins by explaining the rationale and criteria that scientists use to weight connections between evidence and scientific arguments. Learners then read short expository texts on human-induced climate change that incorporate data charts or graphs regarding the incremental trends of carbon emission and of the global temperature. Meanwhile, a scenario was used to guide learners to think like scientists, reasoning and sorting seven evidence statements as well as linking them correspondingly to the arguments presented in the texts. At the end of the unit, three explanatory tasks were given to provide learners with multiple opportunities to synthesize scientific explanations.

17.2.2 Modeling the Relations Among Conceptual Understanding, Scientific Explanation, and Attitude on Climate Change

Understanding the relations between the learning of conceptions, attitudes, and related factors allows educators to design appropriate instructions and determine instructional effectiveness. In the present study, the interplay between knowledge and attitudes was explored to verify the inconclusive findings in the previous literature. Specifically, the influences of individuals' pre-existing knowledge, prior perceptions, and learning of scientific explanation on learning outcomes of knowledge gain and attitude change were investigated as a structural model utilizing PLS-SEM to verify validity. One thing to clarify is that this study does not aim to explore or to verify theoretical structures of action competency in the environmental education literature (e.g., Breiting & Mogensen, 1999; Sass et al., 2020; Stern, 2000). These theories include crucial factors and coherently explain the interplay between and among knowledge and skills, willingness, and actions; however, the components and mechanism of these theories are beyond the scope of the present study. Below, the established literature is reviewed to form the hypotheses of the paths in the structural model.

Critical thinking in terms of how evidence relates to a claim recognizes that prior knowledge is an important prerequisite for determining the adequacy of the evidence and the underpinning concepts or theories (Sherin et al., 2012). However, merely supplementing knowledge is not sufficient to promote conceptual understanding and the ability to provide robust explanations. Lombardi et al. (2013) argued that engaging in critical evaluation of the connections between evidence and arguments triggers conceptual reconstruction. They prompted middle-school learners to weigh and rank the strength and adequacy of evidence related with two alternative claims of causes of climate change. The cohort of students who received the evaluation instruction demonstrated more knowledge gain and better retention in comparison to the cohort of students who experienced climate change activities without critical evaluation instruction. Later, Lombardi et al. (2016) verified these findings showing that critical evaluation ability is a significant predictor of post-instructional knowledge.

Research also shows that engaging individuals in opportunities to reason in scientific discourse may shift their attitude in a particular direction. Sinatra et al. (2012) applied a conceptual change approach to develop and structure persuasive texts based on readers' prior knowledge and beliefs by presenting new information and evidence to contradict readers' current beliefs about climate issues. The results showed that reading persuasive texts about human-induced climate issues significantly promoted undergraduates' attitude change about climate change and their willingness to commit to taking action. In the scientific explanation unit, I carefully structured texts and graphs to engage the participants in reasoning about the discourse conveying humans' role in global warming and supplying the reasons for why immediate actions are needed. Thus, based on these findings, one can hypothesize that learning about scientific explanations may prompt both conceptual understanding and attitude change.

Understanding the mechanisms and processes behind climate change can help individuals understand their interactive role within the climate and the environment (Lombardi et al., 2012; Tasquier & Pongiglione, 2017; Versprille et al., 2017). Lacking appropriate understanding, on the other hand, may hinder individuals from taking appropriate actions. They may also underestimate the importance of the issues or possess false perceptions. Studies have explored the relation between knowledge of and attitudes toward climate change; however, the findings were inconclusive. On the one hand, climate change knowledge was found to be positively related to concerns about climate change. Aksit et al. (2018) observed that content knowledge was a significant predictor of the concern about climate change; greater climate change knowledge was positively related to acceptance of anthropogenic global warming and higher risk perception. A more recent study on Taiwanese undergraduate students (Li & Liu, 2021) also indicates that, after receiving a semester-long general environmental course, students' self-reported knowledge on climate change had a minor but positive correlation with perceived impact and concerns about climate change. On the other hand, some literature suggests that possessing knowledge is rather ineffective in terms of generating attitude and behavior change. Dijkstra and Goedhart (2012) conducted a cross-national survey, but were not able to find a relation between knowledge of climate change and climate change-related or environment-related attitudes.

Based on the previous literature, a predictive model of climate change knowledge, attitude, and quality of explanations is proposed (Figure 17.1) that hypothesizes whether possessing knowledge of climate change supports learning of scientific explanation and leads to better outcomes as post-conceptual understanding. A positive influence of quality of scientific explanation on post perceptions was estimated,

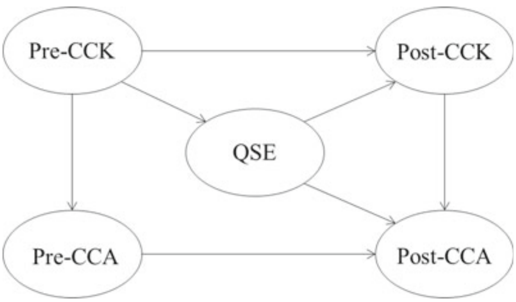

Fig. 17.1 A hypothetical model of the relationships among climate change knowledge, attitude, and quality of scientific explanations. *Note* CCK: climate change knowledge; CCA: climate change attitude; QSE: quality of scientific explanation

since engaging learners in reasoning about or with scientific discourse (e.g., synthesizing or weighting scientific explanations) has promoted attitude change. It is not clear whether knowledge shows a positive influence on climate change attitude since its relation is inconclusive. However, this study expected to verify Aksit et al.'s (2018) finding that a positive relation exists because the participants' objective knowledge was assessed using a similar instrument. Their pre-existing knowledge was also expected to have a strong and positive influence on the post-knowledge; a similar relationship is assumed for the prior and post-instructional attitudes.

17.3 Research Methods

In the present study, a climate change knowledge test and a climate change attitude survey were administered prior to and after the instruction to understand the influence of the module on participants' knowledge and perceptions of climate change. The pre- and post-assessment scores of knowledge and attitude, along with the participants' performance of synthesizing scientific explanations were used to build the hypothesized structural model. The interplay among pre-existing climate change knowledge and attitude, performance of scientific explanations, and the knowledge and attitude post-assessment scores were then investigated using partial least squares structural equation modeling (PLS-SEM). The PLS-SEM has several advantages in comparison to covariance-based SEM (CB-SEM) when used in educational studies (please see a review study, Lin et al., 2020 for more information). This technique was chosen because of the explorative nature of this study.

17.3.1 Participants

Study participants were 120 adults recruited through a recruitment announcement for this experiment on social media. The age of the participants ranged from 20 to 54 ($M = 28.04$, $SD = 7.56$). Nearly half of them were female (48.3%) and over half were non-science majors (55.8%).

17.3.2 Research Instrument and Data Collection

17.3.2.1 The Climate Change Knowledge Test

To measure the participants' pre- and post-conceptual understanding, Versprille et al.'s (2017) multiple-choice diagnostic instrument was adapted. The original instrument included items on topics in climate science (e.g., identifying greenhouse gases, radiative forcing, and impacts of climate change) and chemistry (e.g., gas behavior, bonding, and the electromagnetic spectrum). Three items were eliminated because they were beyond the content coverage (e.g., items on the particulate nature of matter). Three more items were adapted from Lambert et al.'s (2012) instrument regarding the role of the Sun and the sources of greenhouse gases. A self-developed item was added regarding the accumulated concentration of greenhouse gases in the atmosphere. The final version consisted of 13 items, addressing the phenomena of the greenhouse effect at the macro-level (six items), detailed chemistry or physics characteristics (five items), and sources of greenhouse gases (two items).

17.3.2.2 The Climate Change Attitude Survey

To assess the issue-related attitudes, Christensen and Knezek's (2015) survey was used as the main source. The original survey contained 14 items representing beliefs and intentions regarding the climate change issue from Christensen and Knezek (2015), five items from Lombardi et al. (2013) on beliefs about the climate change issue, one item from Maibach et al. (2010), six modified items adapted from Pan and Liu (2018), and eight self-developed items to capture important aspects of the latent variables to depict participants' concerns about and awareness of the importance of the issue. The participants responded to the items on a 5-point Likert scale, ranging from *strongly disagree* to *strongly agree*. Negative items were reverse scored. Factor analysis was conducted on a dataset with a sample size of 211.

Principal component analysis was performed (KMO = 0.91, Bartlett's $\chi^2(561) = 3957.29$, $p < .001$), and Oblique (i.e., Oblimin) rotation was used because I expected the components to be correlated based on my literature review. Five components resulted from the factor analysis with adequate loading for each component, namely: beliefs about causes and impacts of climate change (11 items), intentions regarding climate actions (7 items), efficacy of conquering climate issues (3 items), concerns about impacts of climate change (5 items), and awareness of the importance and seriousness of climate change (5 items). Reliability analysis of the five components in the pre- and the post-surveys revealed Cronbach's alpha values from .74 to .92, except for the component of efficacy of conquering climate issues in the post-survey (Cronbach's alpha = .59).

17.3.2.3 Quality of Scientific Explanations

In each explanatory task at the end of the scientific explanation unit, an argument against human-induced climate change was given with a corresponding data chart or graph. Learners responded to the written explanatory tasks by selecting and circling a data section on the charts as evidence, and explaining how the selected piece of evidence supports the argument. The same process was repeated for the counter-argument. Lombardi et al.'s (2016) four-level rubric was adapted to score the written explanatory tasks. Lombardi et al.'s rubrics were slightly modified according to the task features (see Table 17.2). A higher score indicates a more sophisticated

Table 17.2 The scoring rubric for the written explanatory task

Description	Score
Erroneous reasoning: Uses incorrect evidence to support the argument. Selects correct evidence but does not provide any explanation or incorrectly links to the argument	1
Descriptive reasoning: Correctly connects the data trends to the argument with little or no elaboration. Explanations are synthesized based on a single, short data peak on the chart. No indicator has shown that the learner is able to distinguish the evidence from the explanation	2
Relational reasoning: Explains a causal relationship and links a correct section of data trend as evidence for the argument with appropriate supports. Statements show a sign that the learner is able to distinguish between evidence and the explanation	3
Relational reasoning with elaboration: In addition to the features of *relational reasoning*, a deeper reflection or a more sophisticated consideration of the evidence-argument connection is observed. For example, in addition to using the increasing trends of carbon emissions and of global temperature to support human-induced global warming, the learner comments on evidence from the trend of solar activity to contradict the counter argument	4

ability of selecting appropriate evidence as well as of reasoning and elaborating on how evidence is used to support both sides of arguments on human-induced climate change. Two raters rated the participants' responses with an inter-coder reliability as a Cohen's kappa of 0.86. Inconsistent ratings were resolved through discussion.

17.3.3 Implementation Procedures

Participants were invited to the laboratory. After giving consent, they completed a demographic survey, the climate change knowledge test, and the climate change attitude survey in the pre-assessment. Each participant then began the first unit on building conceptual understanding of global warming individually on a desktop computer. There was no time limit, and participants were allowed to learn at their own pace. After a 5- to 10-minute break upon completion of the first unit, the participants continued with the second unit on scientific explanations. Upon completion of the second unit, the participants took the knowledge test and the attitude survey again as the post-assessment. In general, the participants spent a total of 80 minutes on the online module, and the pre- and post-assessment each took about 20 minutes. Twenty USD was paid to each individual to thank them for their participation.

17.3.4 Data Analysis

To answer the first research question, paired-sampled *t* tests were used to examine the influence of the digital module on the participants' knowledge gain and attitude change regarding climate change. To answer the second research question, PLS-SEM was used to verify the validity of the hypothesized model on the interrelationships between the latent variables including pre- and post-climate change knowledge, attitude, and quality of scientific explanations.

There is an increasing trend of applying PLS-SEM for exploratory research in education. It is a multivariate modeling technique for examining the relationships between the latent variables of a predictive model. A recent review study (Lin et al., 2020) identified 53 research articles published in major e-learning journals since 2009 using this method. The increase in popularity of using PLS-SEM in educational studies may be attributed to such studies not meeting the assumptions of normal data and large sample sizes (Lin et al., 2020).

The indicators and process of the outer model and inner model evaluation followed the guidelines suggested by Lin et al. (2020). For the *outer model evaluation*, indicator loadings were computed to examine indicator reliability. Composite reliability (CR) values and average variance extracted (AVE) were calculated to validate internal consistency reliability and convergent validity, respectively.

To build the structural model, the scores for items of the macro-phenomena of the greenhouse effect (6 items), the detailed chemistry or physics characteristics (5 items), and sources of greenhouse gases (2 items) were each aggregated as the three indicators (named CCK 1, 2, and 3, respectively) for both the pre- and the post-climate change knowledge tests. Responses to the items of the five constructs regarding beliefs about causes and impacts of climate change (11 items), intentions regarding climate actions (7 items), efficacy of conquering climate issues (3 items), concerns about impacts of climate change (6 items), and awareness of the importance and seriousness of climate change (5 items) were each aggregated as the five indicators (named CCA 1 to CCA 5, respectively) for each of the pre- and post-climate change attitude surveys. Scores of the responses to the three written explanatory tasks were used as the three indicators of quality of scientific explanation (QSE).

17.4 Results

17.4.1 Influence of Digital Climate Change on Knowledge Construction and Attitude Change Toward Climate Change

Table 17.3 reports the means and standard deviations of the pre- and post-climate change knowledge tests. Prior to the instruction, participants generally held partial

Table 17.3 Descriptive statistics and the results of the paired sample *t*-test analysis on climate change knowledge

	Pre			Post			
Sub aspects	Items	*M*	SD	*M*	SD	*t*	Cohen's *d*
Greenhouse effect—macro-phenomena	6	3.03	1.22	4.53	0.99	13.00***	1.19
Detained chemistry and physics characteristics	5	2.74	1.21	3.59	1.25	7.16***	0.65
Sources of greenhouse gases	2	1.38	0.65	1.79	0.45	6.58***	0.60
Total	13	7.16	2.30	9.92	1.96	16.01***	1.46

***$p < 0.001$

understanding, receiving above half of the points on each sub aspect. Paired sample *t* tests indicated significant gains from pre- to posttest on all aspects and on the total knowledge scores. Particularly, the participants who attributed the cause of climate change to ozone depletion (Item 1) reduced from 19% in the pretest to 1% in the posttest. The result shows that this digital module successfully and substantially leveraged the participants' understanding of climate change.

Table 17.4 reports the means and standard deviations of the pre- and post-climate change attitude surveys. The results of the pre-survey showed that the participants' perceptions of *causes and impacts of climate change* were high. The participants were also highly *aware of the importance of the issue*. The participants' prior-held *intentions regarding climate actions* and *efficacy* of conquering climate issues were relatively low. They expressed a need and a *willingness to take climate actions*, but they seemed to *lack confidence* in thinking that humans could manage to reduce global warming.

After the instruction, statistically and significantly positive changes were observed in beliefs about causes and effects, concerns about the impacts, awareness of the importance, and the efficacy of making positive changes regarding climate issues (Table 17.4). An improvement in intentions to take climate actions was observed and

Table 17.4 Descriptive statistics and results of the paired sample *t*-test analysis of climate change attitude

	Pre		Post			
Constructs	*M*	SD	*M*	SD	*t*	Cohen's *d*
Beliefs about causes and impacts	4.32	0.45	4.42	0.47	2.72**	0.26
Concerns about the impacts	4.08	0.62	4.25	0.62	3.81***	0.36
Awareness of importance and seriousness	4.38	0.60	4.50	0.59	3.32**	0.30
Intentions regarding climate actions	3.76	0.78	3.88	0.72	1.95	
Efficacy of conquering climate issues	3.78	0.63	3.88	0.64	2.43*	0.19

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

reached a nearly statistically significant level ($t = 1.95$, $p = 0.053$). This module successfully leveraged the participants' perceptions of climate change.

The results indicate that when the learners were supplemented with the needed mental sets and their system thinking was supported with graphical and animated visualizations, radical conceptual development and reconstruction could occur in a short-term intervention. Accompanied with an intervention that engaged the learners in reading persuasive texts and reasoning the linkages between evidence and arguments on climate change may also support positive attitude change toward human-induced climate change.

17.4.2 Modeling the Relations Among the Climate Change Knowledge, Attitude, and Quality of Scientific Explanations on Climate Change

17.4.2.1 The Measurement Model

As the results show (Table 17.5), all indicators were retained for five variables in the proposed model, except for the 'Post-CCK,' in which 'Post-CCK 3' was removed due to its low indicator factor loading. For the indicator reliability, most indicator loadings were higher than 0.7, except for Pre-CCA 2 and 3 (loading = 0.66 and 0.67) and Post-CCA 2 and 3 (loading = 0.69 and 0.66). Chin (1998) suggested that if there are other indicators in the same construct, indicator loadings with 0.5 or 0.6 are considered acceptable. The composite reliability (CR) was calculated to examine internal consistency reliability, and all of the CR values of each variable ranged between 0.78 and 0.90 and exceeded the minimum required value of 0.7. To examine the convergent reliability, the calculated AVE values ranged from 0.55 to 0.64 and met the recommended value of 0.5 (Hair et al., 2011). The discriminant validity was examined with the Fornell-Larcker criterion. The results showed that the square root of the AVE value for each latent variable (0.74–0.80, as the diagonal number of Table 17.6) was greater than 0.5 and larger than the Pearson's correlation coefficients between the variable and the others (in Table 17.6). The internal consistency reliability, convergent validity, and the discriminant validity all met the recommendations of Hair et al. (2011).

17.4.2.2 The Structural Model

The model of the structural relationships among latent variables was examined through a bootstrapping procedure with 5,000 subsamples in order to establish the significance level for each of the theoretical paths. Figure 17.2 shows the significant path coefficients (only significant relationships were drawn), R^2 values, and out loadings for each item.

Table 17.5 The indicator loadings, CR, AVE

Latent variables and indicators	Indicator loading	CR	AVE
Pre-climate change knowledge (Pre-CCK)	–	0.78	0.55
Pre-CCK1	0.78		
Pre-CCK2	0.71		
Pre-CCK3	0.73		
Post-climate change knowledge (Post-CCK)	–	0.77	0.63
Post-CCK1	0.72		
Post-CCK2	0.87		
Pre-climate change attitude (Pre-CCA)	–	0.88	0.61
Pre-CCA1	0.81		
Pre-CCA2	0.66		
Pre-CCA3	0.67		
Pre-CCA4	0.86		
Pre-CCA5	0.87		
Post-climate change attitude (Post-CCA)	–	0.90	0.64
Post-CCA1	0.84		
Post-CCA2	0.69		
Post-CCA3	0.66		
Post-CCA4	0.90		
Post-CCA5	0.89		
Quality of scientific explanations (QSE)	–	0.82	0.60
QSE 1	0.85		
QSE 2	0.76		
QSE 3	0.71		

Note CCK: climate change knowledge; CCA: climate change attitude; QSE: quality of scientific explanation

Table 17.6 The correlations and discriminant validity among the latent variables

	Pre-CCK	Post-CCK	Pre-CCA	Post-CCA	QSE
Pre-CCK	0.74				
Post-CCK	0.59**	0.80			
Pre-CCA	−0.19*	−0.14	0.78		
Post-CCA	−0.18*	−0.10	0.77**	0.80	
QSE	0.38**	0.31**	-0.10	0.01	0.77

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

Notes The diagonal number in the correlation matrix is the square root of the AVE value of each latent variable

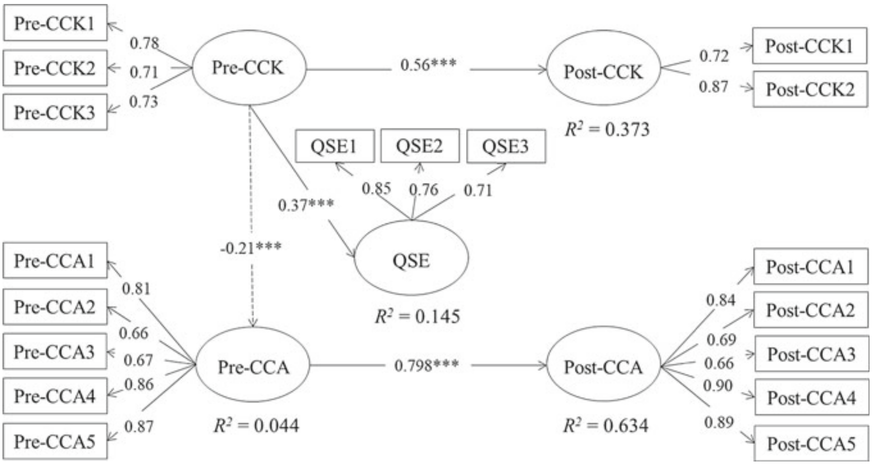

Fig. 17.2 The results of the structural model examination. *$p < 0.05$; **$p < 0.05$; ***$p < 0.01$. Solid lines: positive relation; dotted lines: negative relation

17.4.2.3 Relations Between Prior Conceptions, Quality of Scientific Explanations, and Post-instructional Knowledge on Climate Change

According to Figure 17.2, prior knowledge on climate change was the significant and positive predictor explaining the variation in the quality of scientific explanations (path coefficient = 0.37, $p < 0.001$, adjusted $R^2 = 0.145$). The result indicates that possessing more prior knowledge benefits learning of scientific explanation. This may be attributed to the facilitative role of prior knowledge on selecting appropriate evidence and judging the adequacy of evidence-claim connections. However, the relations of scientific explanation performance with the knowledge posttest and with the post attitude survey were not significant. Unexpectedly, the hypotheses that reading persuasive texts and learning about scientific explanations would promote conceptual reconstruction and attitude change were not supported.

17.4.2.4 Relations Among Prior Knowledge, Prior-Held Attitude, Post-instructional Knowledge, and Post-instructional Attitude Toward Climate Change

Prior knowledge and prior-held attitude were each unique positive predictors of post-climate change knowledge (path coefficient = 0.56, $p < 0.001$, adjusted $R^2 = 0.373$) and post-climate change attitude (path coefficient = 0.80, $p < 0.001$, adjusted $R^2 =$ 0.634), respectively. Learners with higher prior knowledge of climate change were more likely to experience conceptual construction or reconstruction that resulted in better conceptual understanding in the post-assessment. Likewise, participants who perceived higher levels of beliefs or concerns at the beginning were more likely to reveal stronger attitudes or perceptions after receiving the climate change module.

Prior climate change knowledge, however, was a negative predictor of the prior-held attitudes (path coefficient $= -0.21, p < 0.001$, adjusted $R^2 = 0.044$), whereas the relation between post-climate change knowledge and attitude was insignificant. Prior to the instruction, the participants who had more knowledge of climate change were likely to show less beliefs, concerns, efficacy, or intentions. This negative relation may be diminished due to receiving the intervention. The hypothesis regarding a positive influence of climate change knowledge on related attitude was not supported.

17.5 Discussion

The present study responded to the call for research to develop innovative climate change instruction to foster literate citizens. Literature and theories of science education were applied in the design. I have further described how learners' characteristics including their perceptions of the climate issues, related prior knowledge, and learning of scientific explanations may play a role in their reasoning and learning in the digital module.

The findings of the current study indicate that the adult learners on average demonstrated a fair level of prior knowledge and a high level of prior-held perceptions regarding cause and impact, concerns, and awareness of the importance of the climate change issues. This finding may be partially attributed to the recruitment of participants from social media. This recruitment approach may have preselected individuals who were already positively disposed to climate change. Despite the sampling bias, substantial gains on conceptual understanding and positive attitude changes were observed. With a theory-driven design, the results show that this self-directed, digital module was effective in terms of helping adults sufficiently acquire conceptual change knowledge and a significant shift in their attitudes toward human-induced climate change, even when their perceived beliefs, concerns, and awareness of the issues were already high in the pre-assessment. By adding the explanation unit which aimed to promote conceptual change and to persuade attitude change, at least for people who are already concerned about climate change in the first place, findings of the present study show a promising sign of raising individuals' understanding and of altering their attitudes toward climate change with a short-term, one-shot intervention.

In terms of the relations between climate change knowledge, related attitude, and ability of scientific explanation, the current study identified a significant path of how individuals' prior knowledge related to their quality of scientific explanation. A positive role of prior knowledge on learning about climate change explanations is confirmed. This finding is in line with the consistent findings regarding prior knowledge as an important factor influencing learners' learning and performance in socioscientific contexts (e.g., Chang et al., 2020).

Next, the study extends and examines the potential of promoting conceptual development and attitude through teaching scientific explanations with persuasive texts. Research has indicated that persuasive texts structured with a conceptual change approach significantly promote attitude change and willingness to commit to taking action (Sinatra et al., 2012). A unit of instruction that engaged learners in critically evaluating connections between evidence and arguments also enhanced conceptual understanding (Lombardi et al., 2013, 2016). In this study, the texts and graphs of the entire module were carefully structured to engage the participants in reasoning in discourses that conveyed humanity's role in global warming and in supplying the reasons for why immediate actions are needed. While significant improvements were observed in both the knowledge and attitude measurements, no significant or direct relation was found for the participants' explanation quality with their post-instructional knowledge or attitudes. The explanation unit may promote learning of conceptual understanding and trigger attitude shift in some way, but not through directly enhancing the quality of the explanations. There may be other unidentified variables that are worth further clarification.

For the relations between knowledge of and attitudes toward climate change, previous findings were inconclusive. Research indicates that climate change knowledge showed a small or insignificant relationship with related attitudes (e.g., Dijkstra & Goedhart, 2012; Li & Liu, 2021). Aksit et al. (2018) attributed findings of these small or insignificant relations to the selection of instrument. They claimed that assessing subject knowledge using a self-rated survey may underestimate the influence of knowledge. Instead, they assessed learners' objective knowledge using a diagnostic instrument and found a positive and predictive role of climate change knowledge in the acceptance of anthropogenic global warming and higher risk perception. Following Aksit et al.'s suggestion, the present study utilized a diagnostic instrument to assess objective knowledge, but a negative relation was observed. Unlike Aksit et al.'s study, I found that individuals with more knowledge of climate change were less concerned about the impacts, and gave lower ratings for the importance and seriousness of the issue. They also perceived less efficacy in conquering climate issues prior to the instruction. A similar negative relation was previously reported in Kahan et al. (2012), in which people with higher scientific literacy and numerical reasoning capacity were less concerned about the risks associated with climate change. The negative relation between knowledge and attitude in the pre-assessment was diminished after the instruction. It seems that the interrelations between understanding and perceptions of climate issues are more complex than the current model, and there are other cognitive or affective factors which may shape people's understanding and views about climate change (Kahan et al., 2012).

Last, while the digital module shows the effectiveness of promoting both conceptual construction and attitude change, the PLS-SEM result reveals that prior knowledge was the unique positive predictor, explaining 37.3% of the variance in the post-climate change knowledge. Considering the relatively small influence contributed by prior knowledge, it is reasonable to attribute the significant improvement of conceptual understanding to learning with the module. The initial attitude also plays a positive role in revealing a stronger influence on the post-instructional perceptions, explaining 63.4% of the variance. Although the instruction successfully shifted individuals' attitudes about climate issues, still, their prior-held perceptions were the more predominant factor.

17.6 Conclusions

There is an emerging global consensus viewing climate change education as an approach to addressing climate urgency. Accumulative efforts have been made, but little has been achieved due to the abstract nature of the phenomena and the cognitive and psychological barriers to understanding climate change issues. To resolve climate urgency, it is essential to not only equip citizens with the ability to participate in related discussions and adequate knowledge to make informed decisions, but also to enhance their awareness of the issues and to instill in them strong intentions and the confidence to take mitigation and adaptation actions. Instructional interventions that aim to achieve these goals need to innovatively draw on theoretical and empirical works. Through carefully integrating pedagogical approaches to supplement essential knowledge structure as a stepping stone and to subsequently engage learners in reasoning and evaluating claims in persuasive texts, knowledge gain, competency raise, and attitude change may be jointly found. Findings of the study shed light on designing effective pedagogical approaches to overcome some resisting barriers in climate change education.

The study also contributes to a model of relations among climate change knowledge, attitude, and learning of scientific explanations of climate change. Although deficiency of knowledge may explain individuals' lack of climate actions or intentions to some extent, the findings reveal that neither supplementing knowledge nor equipping people with the competency of scientific literacy alone can directly shift their beliefs. While findings of the present study help better understand the underpinning mechanism of the instruction and clarify the influential role of scientific explanation, the puzzle that bridges the cognitive and affective factors of climate change remains unresolved. A limitation of this study is that only the effect of attitude change on climate actions was investigated, rather than directly assessing behavior change in this study. Researchers in environmental education literature (e.g., Breiting & Mogensen, 1999; Sass et al., 2020; Stern, 2000) have proposed theoretical structures of action competency that include crucial factors to coherently explain the interplay between and among knowledge and skills, willingness, and actions. Future curriculum design and research on climate change education should seek to examine and verify the interplay between and among the cognitive and affective variables. More efforts should be devoted to incorporating affective variables (e.g., hope or risk perceptions) and to exploring their influence on learning and performance regarding controversial issues such as climate change.

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