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'The Hole in the Sky Causes Global Warming': A Case Study of Secondary School Students' Climate Change Alternative Conceptions

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Abstract

This study identified secondary school students' alternative conceptions (ACs) of climate change and their resistance to instruction. Using a case-based approach, a diagnostic test was administered to Secondary 3 male students in a pre-test and post-test. The ACs identified in the pre-test were on the causes of climate change, the natural greenhouse effect and its properties, the enhancement of the greenhouse effect, the elements involved in heat-trapping and their characteristics. There were also notable ACs on the effects of climate change, mostly on how the phenomenon is related to non-atmospheric events such as tsunami, earthquakes, acid rain and skin cancer. The students confuse the Montreal with the Kyoto Protocol as the primary treaty aimed at curbing greenhouse gas emissions. Whereas there was significant improvement in students' understanding in the post-test, the distribution of responses for each of the ACs showed that the reduction in erroneous responses was not sufficient to reject the ACs fully. The authors recommend that instruction should move beyond patchwork pedagogy to a more explicit acknowledgement, incorporation and direct refutation of misconceived knowledge structures.

Keywords: Climate change, geography education, alternative conceptions (ACs), resilient ACs, Singapore

Introduction

Climate literacy is an essential life skill. However, in spite of its acknowledged relevance, climate knowledge remains to be largely made of inaccurate and incomplete conceptualizations (Chang & Pascua, 2016; Wang, 2004) in which a great disconnect is

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observed between "actual climate science knowledge and perceived knowledge" (McCaffrey & Buhr, 2008). To this, several scholars have warned of the negative consequences of the perpetuation of false understanding on the phenomenon (Harrington, 2008; McCaffrey & Buhr, 2008). McCaffrey and Buhr (2008) emphasized for instance that in the absence of understanding of what carbon is and what it does to the climate system, introducing policies targeted at changing attitudes and behavior is futile and even counterproductive in the long run.

Building a climate literate citizenry necessitates a multi-disciplinary approach that straddles the broad fields of the social and natural sciences. Teaching the topic requires pedagogies that demand for a critical investigation of man's interaction with the environment (Dupigny-Giroux, 2010). In this study, the authors situated the analysis of building climate literacy through investigating the knowledge base of secondary school students in Singapore. Specifically, the study aimed to determine learners' alternative conceptions of climate change and whether these are successfully corrected by classroom instruction. Using a case-based approach, pre-test and post-test were administered, directed at the diagnosis of ACs and the degree to which these are resistant to instruction. It is a part of a continuing project designed to understand the manner in which climate change as a topic in geography education is learned in the city-state (Chang & Pascua, 2014; Chang & Pascua, 2016; Pascua & Chang, 2015).

This study is a confirmatory research to verify the results and strengthen the arguments presented by the authors in an earlier study, which used the time-series design. In said paper, the first draft of the instrument was employed to document the effectiveness of intervention-oriented instruction in correcting students' ACs (Pascua & Chang, 2015). There were design enhancements that this current study aimed to address. First, there was an assisted intervention in the time-series study whereas there was none in this present study. Second, whereas the whole class was considered as a single respondent in the time-series (N=1), this study regarded the participating cohort as the sample of the population and each student as a respondent. Third, the discrimination index was computed for the current study, which was not possible to employ in the time-series design. Along with the difficulty index, the discrimination index detects test-item quality by comparing the scores of students of different ability levels. A stronger instrument is obtained as a result and a mode of quantification is introduced in identifying ACs. The key question that guided the research was, what are alternative conceptions (ACs) held by students about climate change?

In climate change education research, numerous studies (See Table 1) have documented the occurrence of ACs but there had been lesser attention accorded to inquiries on the degree to which ACs are resilient to classroom instruction. The research reported here intends to address this gap and ultimately, it aims to add to the body of literature advocating the building of climate literacy through understanding how learners approach climate change learning, and contribute pedagogical insights on how the topic should be tackled in the curriculum of secondary school geography.

Table 1.
Alternative Conceptions

Alternative conceptions	Authors
"The hole in the sky is causing global warming" Conflation of ideas about the ozone layer and the greenhouse effect	(Arslan, Cigdemoglu, & Moseley, 2012; Boon, 2010; Chang & Pascua, 2016; Çimer, Çimer, & Ursava, 2011; Dawson & Carson, 2013; Hansen, 2010; Ikonomidis, Papanastasiou, Melas, & Avgoloupis, 2012; Lambert, Lindgren, & Bleicher, 2012; Lee, Lester, Li, Lambert, & Jean-Baptiste, 2007; Liarakou, Athanasiadis, & Gavrilakis, 2011; Mower, 2012; Ocal, Kisoglu, Alas, & Gurbuz, 2011; Punter, Ochando-Pardo, & Garcia, 2011)
Unable to identify most of the greenhouse gases; believes CFCs are the key greenhouse gases responsible for anthropogenic climate change	(Bodzin et al., 2014; Boon, 2010; Bozdogan, 2011; Chang & Pascua, 2016; Dawson & Carson, 2013; Hansen, 2010; Liarakou, et al., 2011; McCuin, Hayhoe, & Hayhoe, 2014; Punter, et al., 2011)
Erroneous conceptions on the causes of global warming (e.g., nuclear power, solar energy, natural gas not a fossil fuel)	(Boylan, 2008; Coşkun & Aydın, 2011; Liarakou, et al., 2011; Ocal, et al., 2011; Yazdanparast et al., 2013)
Unable to differentiate the natural and enhanced greenhouse effect	(Arslan, et al., 2012; Boon, 2010; Chang & Pascua, 2016; Dawson & Carson, 2013; Lee, et al., 2007; Liarakou, et al., 2011; Ocal, et al., 2011)
Climate change is believed to be solely a human-induced phenomenon; no understanding of the natural causes of climate change	(Bodzin, et al., 2014; Chang & Pascua, 2016; Çimer, et al., 2011)
Confusion on the effects of climate change (e.g., the sea level will stay the same, the effects are uniform, hotter climate every single year, skin cancer, earthquakes, tsunamis, acid rain)	(Arslan, et al., 2012; Boon, 2010; Chang & Pascua, 2016; Coşkun & Aydın, 2011; Lee, et al., 2007; Liarakou, et al., 2011; Mower, 2012; Ocal, et al., 2011; Shepardson, Niyogi, Choi, & Charusombat, 2009; Yazdanparast, et al., 2013)
Unfamiliarity with mitigation and adaptation strategies (e.g., the Kyoto Protocol is confused with the Montreal Protocol, 'good things' like clean beaches can help ameliorate the enhanced greenhouse effect, the use of unleaded gasoline would help reduce	(Arslan, et al., 2012; Boyes, Stanisstreet, & Yongling, 2008; Ikonomidis, et al., 2012; Liarakou, et al., 2011; Yazdanparast, et al., 2013)

global warming).	
Global climate change means pollution in general	(Boyes, et al., 2008; Punter, et al., 2011; Shepardson, et al., 2009)
Ultraviolet radiation is the culprit in global warming	(Çimer, et al., 2011; Dawson & Carson, 2013)

Method and Procedures

The case study approach was used in the diagnosis of ACs. The methods, sample and instrument were aligned to show the details of how a subgroup within the population, in this case two classes of students from a boys school, learn the topic of climate change.

While various approaches to determine ACs have been employed (Boon, 2010; McNeill & Vaughn, 2012; Punter, et al., 2011) this research made use of a diagnostic test patterned after Treagust's (Treagust) two-tier system. The tiered test is composed of the Content Tier, which assesses subject matter knowledge and the Reason Tier, which examines supporting conception underlying content knowledge. Using a multiple-choice questions (MCQ) format, the items are specifically designed to identify alternative conceptions (ACs) in a defined domain.

A two-tiered test provides insight into students' reasoning process that could not be measured directly through other methods. For instance, it allows for the analysis of how students reason with both their domain-specific and domain-general knowledge (Tsui & Treagust, 2010). The test had been implemented extensively in detecting alternative conceptions from when Treagust (1988) popularized its use; in inorganic chemistry (Tan, Goh, Chia, & Treagust, 2002), malaria (Cheong, Treagust, Kyeleve, & Oh, 2010), genetics (Tsui & Treagust, 2010), internal transport in plants and the human circulatory system (Wang, 2004) among others.

Student Sample

Respondents to the test were 54 male students at Secondary 3 Level (ages 14-15 or Grade 8), all enrolled in a geography course at a boys' school in Singapore. In this study, the sample was chosen from an all-boys school as it does not seek to examine differences in performance between genders (refer to previous works cited), but instead focus on controlling this aspect of the demographics in the sample. The cohort was split in two classes taught by the same teacher. The instrument was administered to the students for a half-hour period for both the pre-test and the post-test. All class sessions on the topic of climate change were recorded on video.

Part I: Instrument building

The Instrument, Validation, Piloting

The two-tiered multiple choice diagnostic test was developed in three phases using procedures defined by Treagust (1988): a) defining the content domain, b) identifying students' alternative conceptions and c) development and validation of instrument.

Defining the Content Domain

An extensive literature review was done to ascertain the features of ACs held by students. The patterns identified in the review were verified for content domain fit vis-à-vis secondary school geography contextual to Singapore. This validation was completed through the examination of textbooks, syllabi and teaching guides provided by the Ministry of Education.

Identifying Students' Alternative Conceptions

Collected information from the literature was further substantiated by data gathered from the population under study. The first phase of the research, a baseline study of secondary school students' understanding of climate change, was earlier conducted with 11 participating schools in Singapore. Through performance tasks and interviews, it was ascertained that Singapore students share the same set of ACs with their global counterparts, in addition to several Singapore-specific ACs (Chang, 2014). The findings from this preliminary research served as the basis for this current study.

Development and Validation of Instrument

Face and content validity tests were performed through a rigorous item-by-item examination of the questionnaire in a roundtable discussion attended by two geography university lecturers, an education research specialist and a secondary school geography teacher. The revised instrument was first used in a quasi-experiment study in another school (Pascua & Chang, 2015). Said study yielded substantial insights that were integral to improvements introduced for the second draft. The original set of questions was subjected to a pilot test. Furthermore, calculations for reliability, discrimination and difficulty indices were completed to ascertain the suitability of the items. Additional modification and refinement of the questionnaire resulted to a trimmed down list of 22 questions (See Appendix for a sample question. For the full questionnaire, email correspondence should be addressed to the article authors).

In perspective, the topic under investigation is covered in the Secondary 3 geography curriculum. Climate change is featured with the following sub-topics: change in the climate for the last 150 years, the greenhouse effect, the enhanced greenhouse effect, the natural causes of climate change, anthropogenic causes of climate change, the impact of climate change, and responses to climate change.

Part II: Implementation of the Instrument

The Lesson

This is the second instance in which the instrument was implemented, the first one being the quasi-experiment previously mentioned (Pascua & Chang, 2015). Results of the quasi-experiment confirmed the resilience of ACs in students' mental models. Without the use of intervention-oriented evaluation in the design, it was apparent that the students' ACs would have persisted post-instruction. In the second set-up, the researchers wanted to discount researchers' influence from the intervention and allow a teacher-led pedagogy to refute identified ACs.

Ms Lee (pseudonym), the participating geography teacher, is a very experienced educator. She was given the liberty to use her preferred pedagogical tools to teach the topic. Prior to the classroom sessions, the teacher was briefed by the researchers on the results of the quasi-experiment and the objectives of the second intervention. The pre-test was administered a day before Ms Lee started teaching on the topic of climate change. While consent from both the parents and participants were sought in writing, the students had no prior information on the content of the test. Correspondingly, the post-test was administered a day after the conclusion of sessions on climate change. Of the 56 students who took the test, eight (8) were identified to have been errant based on repetitive choice combinations given in either the pre-test or post-test. These were deleted from the roster, thus, N=46. Ms Lee's timetable is as follows:

Table 2.
Timetable of topics

Days	Topic
1	Film showing (The Day After Tomorrow)
2	Preliminary discussion on climate change through a discussion of the students' reflections on the film
3	The natural and anthropogenic causes of climate change
4	The natural and the enhanced greenhouse effect
5	Effects of climate change
6	Responses to climate change

Scoring and analysis

In scoring the assessment events, each item in the questionnaire was computed for Content (Tier 1), Reason (Tier 2), and Understanding (Tiers 1 &2) scores. A point was given to an item in the Understanding score only if the correct combination of answers for both Content and Reason tiers were supplied. Relevant statistics were computed such as the measures for reliability, central tendency as well as discrimination and difficulty indices for all scores.

A paired t-test was used to determine whether there was movement in scores from the pre-test to the post-test. Item Response Analysis (Jiuan, Wirtz, Jung, & Keng) was conducted for both test events to identify which ACs were successfully refuted, which ones were especially resilient, and whether new ACs were formed during the course of instruction. A wrong answer was considered an AC if it constitutes ≥10% of all answers in the pre-test. A resilient alternative misconception, one in which a wrong belief was tenaciously maintained in spite of instruction, referred to wrong answers that were ≥10% of all answers in the post-test. The ACs were categorized thematically in the discussion of results.

Findings

The teacher commenced teaching the topic of climate change by showing the 'The Day After Tomorrow' in the first class session. In a worksheet distributed the next day, the students were asked to students to summarize the plot of the movie, state possible

causes of change in climate as depicted in the video, argue whether the scenario shown in the video is likely to happen in the future, and to state their ideas of the consequences of climate change. The students were given 10 minutes to answer the questions, after which several students were called out to recite their answers in exchange for points. This teaching style was consistently used throughout the remaining sessions. The students were grouped into pairs or threes on the last day to report on the cause, effects, and management of climate change.

The pre-test scores showed that the students have low understanding of climate change concepts as indicated by a mean score of 7.57 (3.89) out of a maximum score of 22. The test's difficulty index ranged from moderate to difficult, with a mean difficulty level at 0.34. At this point, the level of difficulty was expected to be high considering that the topic was yet to be learned by the respondents. The authors made a conscious decision not to discard difficult items with the intention to observe change in cognition in the post-test.

To calculate for the discrimination index, a point bi-serial correlation coefficient was computed for each of the items to determine whether students of higher ability were able to perform better than their peers with lower ability. The mean discrimination index is .39. Overall, the test was of moderate difficulty and discrimination power. The Cronbach alpha is calculated at .724 when both tiers of the test items were scored together, signifying that the instrument is well within the accepted level of reliability. Calculated statistics are summarized in Table 3.

Table 3.
Instrument Statistics

	Test Statistics
N	46
Max score	22
Mean Score (Marsden)	7.57 (3.89)
Median/Mode Scores	6.5/6
Min/Max scores	1/19
Cronbach's coefficient alpha value	.724
Discrimination Index	
Mean	.39
No. of items (range $.8 \leq d < 1$)	0
No. of items (range $.6 \leq d < .8$)	1
No. of items (range $.4 \leq d < .6$)	9
No. of items (range $.2 \leq d < .4$)	11
No. of items (range $0 < d < .2$)	1
Difficulty Index	
Mean	0.34
No. of items (range $.8 \leq d < 1$)	0
No. of items (range $.6 \leq d < .8$)	1

No. of items (range .4 ≤ d <.6)	8
No. of items (range .2 ≤ d <.4)	7
No. of items (range 0 < d <.2)	6

Further, an Item Response Analysis showed that a very high proportion of the students answered correctly the Content Tier only. Consistent with the literature, the patchiness in understanding characterized by the mixing of incorrect and correct concepts was apparent in the pre-test.

Alternative Conceptions

There was a significant difference in the scores for the pre-test (M=7.57, SD=3.89) and the post-test [(M=12.83, SD=4.46); t (46) =8.59, p = 0.000], indicating that there was notable improvement in the students' climate change reasoning as a result of instruction. The post-test scores also had lower mean discrimination index— an indication that students from both the high and low ability levels gained substantial understanding of the topic. The IRT determined that several ACs were refuted successfully by instruction (<10%). These were replaced by the following correct concepts:

1. Water vapor is a greenhouse gas
2. Anthropogenic climate change is due to the burning of fossil fuels
3. The enhancement of the greenhouse effect means there are more types and higher concentration of greenhouse gases in the atmosphere
4. Not all greenhouse gases destroy the ozone
5. The climate naturally changes due to variations in solar radiation
6. Greenhouse gases trap heat in the form of long wave radiation
7. Chlorofluorocarbons (CFCs) are not the main gases responsible for the enhancement of the greenhouse effect
8. Pollution is not the main cause of the enhancement of the greenhouse effect

However, while most of the ACs decreased in count in the post-test, majority of known ACs were retained (≥ 10%), in addition to new ones detected. Tables 4-9 summarize the ACs and signpost the movement in scores from pre-test to post-test. The numbers indicated refer to percentages and not frequency counts.

Table 4.
Climate change fundamentals

	Pre-test	Post-test
Climate change refers solely to global warming. Global cooling is not climate change	43	20
Climate change is a natural phenomenon because typhoons and hurricanes are all due to natural causes	--	11
Natural gas is not a fossil fuel	26	33

The assimilation of new concepts was facilitated in some areas but was not successful in others. For instance, the belief that climate change refers solely to global warming (20%) in spite of instruction that reiterated on global cooling as an alternate phenomenon was retained. In addition, while students correctly identified natural

climate change as due to solar radiation variation, they have also developed the perception that climate change is a natural phenomenon owing to the understanding that typhoons and hurricanes are due to natural causes (11%).

Natural gas, a fossil fuel regarded for its cleaner properties compared to oil and coal, is used primarily in the transport sector in Singapore. A large percentage (33%) did not think natural gas is a fossil fuel. In fact, this misconception increased from 26% in the pre-test. The videos and field notes confirm that the teacher categorized natural gas as a fossil fuel in her instruction.

Table 5.
Natural greenhouse effect

	Pre-test	Post-test
Shields the Earth from the sun, preventing too much sunlight from reaching the Earth's surface	30	24
Takes place mostly in the ozone layer. Heat released by the Earth is trapped in the ozone layer	30	24

The conception of the natural greenhouse effect, while it improved significantly, remained flawed. Specifically, the view of the system as a shield from the sun (24%) was still predominant. The juxtaposition of the greenhouse effect with the ozone layer was evident, as it is believed that the greenhouse effect and the process of heat-trapping takes place in the ozone layer (24%).

Table 6.
Enhanced greenhouse effect

	Pre-test	Post-test
The Ozone hole enhances the greenhouse effect.	48	31
Radioactive wastes from nuclear power plants are a cause of the enhanced greenhouse effect.	20	11
Singapore contributes mainly to the enhancement of the greenhouse effect through the use of CFCs	51	14
Heat from global warming destroys ozone molecules	15	15

The Ozone explanation persists as the primary reason for the enhancement of the greenhouse effect (31%) in addition to nuclear power radioactivity (11%) and the belief that Singapore's CFC emissions contribute mostly to the city-state's carbon footprint. In addition, the perception that global warming- generated heat is the culprit to the destruction of the ozone layer remains unchanged (15%) in the post-test.

Table 7.
Radiation and the process of 'heat trapping'

	Pre-test	Post-test
Sun rays, absorbed by the atmosphere	78	44
Ultraviolet rays	30	24
Visible light	--	16

The conception on the nature of radiation that is absorbed and re-emitted is riddled with differing alternative conceptions. While earlier it was found that students have correctly identified infrared rays as the type of radiation trapped by greenhouse gases, some still predominantly believed that these are solar rays absorbed by the atmosphere (44%) in the form of ultraviolet radiation (24%). Class discussions on the different types of radiation from the sun resulted to a new AC that visible light (16%) is absorbed instead of infrared rays.

Table 8.
Effects of climate change

	Pre-test	Post-test
Climate change is likely to trigger tectonic plate movements, thus earthquakes and tsunami	28	30
Tsunami and earthquake will be triggered by increased global atmospheric temperature	--	19
Acid rain	19	11
Skin cancer due to ultraviolet rays	78	44
Increased risk of skin cancer as greenhouse gases block radiation from escaping into space	--	11

The association of tsunamis and earthquakes with climate change was resilient. In retrospect, the teacher included plate tectonic activities as a reason for geologic climate changes. While she clarified that there are no direct links between recent climate changes and the two mentioned phenomena, the related AC in fact increased in number (30%). In addition, a new AC emerged that climate change will trigger tectonic plate movements (19%).

Acid rain (11%) and skin cancer (44%) were persistent ACs. Interestingly, a new conception in the post-test is the belief that greenhouse gases and not ultraviolet rays will cause skin cancer (11%).

Table 9.
Management of climate change

	Pre-test	Post-test
The Montreal Protocol addressed climate change by recommending a cap on greenhouse gas emissions	72	51
The Montreal Protocol addresses climate change through banning CFCs	--	13

The pilot test revealed that students were knowledgeable of the different mitigation and adaptation strategies for climate change such as the very popular 3Rs (reuse, reduce, recycle) and the preference for public over private transport. The least understood concept was the distinction between the Kyoto Protocol and the Montreal Protocol, treatises that both target global environmental issues, with the latter believed to be the treaty for climate change (51%). A misconception that emerged in the post-test was the belief that the Montreal Protocol addresses climate change through banning

CFCs (13%). This is despite the fact that the Montreal Protocol had been discussed in lower level geography on the topic of Ozone layer depletion.

Discussion and Conclusion

This study intended to investigate students' basic knowledge of the geo-scientific characteristics of climate change as taught in secondary school geography in Singapore. It took stock of current ACs and their embeddedness in students' domain understanding.

The two-tier diagnostic test was facilitative in defining the faulty associations used by students between concepts. Specifically, it provided an avenue to objectively assess the reasons students attach to certain content knowledge. Previously, a time-series study (Pascua & Chang, 2015) revealed the presence and resilience of ACs. While said study provided valuable insight as to how embedded prior knowledge bars effective learning of accurate concepts, there were several aspects that were not taken into account, which this current study aimed to address. Such include the calculation of discrimination power of the items and the test as a whole. In addition, the time-series study was essentially a 'guided' inquiry such that the researchers were actively involved in designing the course of instruction. This pre-test and post-test approach, on the other hand, had no researcher-initiated testing akin to the method implemented in the time-series study. The goal was to document how status quo teaching shapes (mis)understanding. The pre-test and post-test were completed to determine whether there was positive, negative and significant changes in students' conceptual understanding.

An earlier paper by the authors categorized ACs according to the incorrectness, incoherence and incompleteness of the mental models Singaporean students form about climate change. While the results of said study were based on interviews, this article provided descriptive data on the prevalence, and resilience, of ACs through a quantification scheme aided by the two-tiered diagnostic test. Such approach provides for a more robust empirical understanding of the subject.

The pre-test showed that the students held multiple ACs, with many who were only able to correctly answer the Content Tier, so that there were many instances of mixing of incorrect and correct concepts. Consistent with the literature, the ACs were on the lack of understanding of climate change as both a natural and human-induced phenomenon, the natural greenhouse effect and its properties, the enhancement of the greenhouse effect, the elements involved in heat-trapping and their characteristics. In addition, there were also notable ACs in the students' understanding of the effects of climate change, mostly on how it is related to other non-atmospheric events such as tsunami, earthquakes, acid rain and skin cancer. There is also widespread confusion between the Montreal and Kyoto Protocols as the primary treaty aimed at curbing greenhouse gas emissions.

The post-test indicated that while there was significant improvement in understanding as indicated by the refutation of several ACs, most were retained albeit reduced in count. Indeed, while the distribution of responses for each of the ACs was

reduced, such was not sufficient to reject the ACs fully. This is in addition to several others that were detected post-instruction.

In conjunction with the findings of the time-series study, this research confirmed the resilience of climate change ACs in the face of non-refutational instruction. Indeed, whereas there was no explicit intervention introduced, the research was able to document that unless direct refutation becomes the goal of instruction for this topic, ACs remain intact in students' conceptual understanding. Further, the results confirm von Aufschnaiter and Rogge's (2010) claim that deficient understanding is due mainly to missing conceptions and the lack of explanatory conceptual understanding available for learners. At the grain size of a single idea, irregularities could be detected in the form of incomplete conceptualization. The corrected ACs discussed are testament to this. Gaps in an incomplete idea can be filled under this condition of prior knowledge (Chi, 2008). However, several new concepts were not easily accommodated as they were tenaciously in conflict with prior knowledge. The conflict between infrared, ultraviolet and visible light as the type of radiation that is absorbed and re-emitted is an example. On the other hand, water vapor as a greenhouse gas was successfully assimilated because said concept did not have to replace another idea.

When concepts are organized to signify relationships and interrelatedness, mental models are formed as internal representations of an external structure. Mental models are simulacra following an if-then pattern that could be run mentally to depict changes and generate predictions and outcomes. Much like individual beliefs, mental models may be sparse in details. A flawed mental model uses a coherent but incorrect mental model different predictions and explanations, and may contain different elements from the correct model (Chi, 2008). Further, Chi (2013) posits that resilient ACs are a result of miscategorisation of processes as sequential process when in fact they are of the emergent kind. While the ACs identified were proven to have been resistant to refutation, the authors maintain that the models, both the ACs and the correct one, were at the same categorical level (as a sequential process), therefore category shift was not necessary. It is reiterated that the failure to correct ACs were due to the lack of direct and iterative refutation addressing the core assumptions of the correct climate change model vis-à-vis the misconceived models. Thus, the misconceived models were not incommensurate with the correct model as the assumptions contradict each other on the same dimension—as processes that follow the sequential pattern.

The authors are cognizant of the limits of the case study approach especially on the validity of results when generalizing across contexts. Certainly, demographics such as gender, age group, ethnicity, school type and other factors have varying influences as to the extent and nature of knowledge that is cultivated. It is therefore recommended that supplementary research be conducted with these factors taken into account. Findings of this study are most relevant and useful to teachers and curriculum-makers. It highlights the often neglected influence of ACs on classroom teaching and consequentially, on the quality of student learning. Fine-tuning the curriculum to include the detection and refutation of ACs is endorsed. The authors recommend that instruction should move

beyond patchwork pedagogy to a more explicit acknowledgement, incorporation and direct refutation of misconceived knowledge structures.

Nonetheless, this inquiry attests to the assertion that global climate change literacy as a goal faces a formidable adversary in the form of tenacious alternative conceptions. Indeed, the onus of equipping a generation of critical thinkers about climate change rests not just on a 'storm- ready' curriculum (Kagawa & Selby, 2012), but also with pedagogical readiness and awareness of educators on the complexities involved with prior knowledge that cloud students' understanding of the topic.

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Biographical statement

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Appendix

Sample Questions

1. The heat generated from burning refuse (incineration) contributes to global warming

A. True

B. False

The reason for my answer is:

a. The heat rises to the atmosphere, worsening global warming

b. Particles released from burning create holes in the ozone layer

c. It is the greenhouse gases released that contribute to warming

d. Others: _____

2. The Montreal Protocol aims to

A. Reduce greenhouse gas emissions of signatory countries

B. Come up with measures to address climate change

C. Neither A nor B

D. Both A and B

The reason for my answer is:

a. The protocol puts a cap in the emission of greenhouse gases, particularly carbon dioxide

b. The protocol bans the use of chlorofluorocarbons (CFCs)

c. The protocol puts a cap on the use of methane

d. Others: _____