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Remediating Misconception on Climate Change among Secondary School Students in Malaysia

Abstract

Existing studies report on secondary school students' misconceptions related to climate change; they also report on the methods of teaching as reinforcing misconceptions. This quasi-experimental study was designed to test the null hypothesis that a curriculum based on constructivist principles does not lead to greater understanding and fewer misconceptions on acid rain, global warming, greenhouse effect, and ozone layer depletion than the traditional Malaysian curriculum. For this purpose two classes from two different schools were randomly assigned to experimental ($N = 35$) and control condition ($N = 38$). Following the intervention, an ANCOVA with pre-test as the covariate showed statistically significant differences in understanding for all four topics; additional interviews with randomly selected students from experimental and control group further underscore the findings. Implications are discussed.

Keywords: Remediating Misconception, Climate Change, Secondary School, Biology Curriculum

Introduction

We can find out almost daily – e.g., by watching the news – that climate change is one of the biggest issues facing humanity today. Climate change refers to changes that entail the alteration of the composition of the global atmosphere (United Nations Framework Convention on Climate Change 1992). If it is thought to have been caused by human activities, climate change can be addressed partially by prompt action (IPCC 2007a). One way of imparting the knowledge required for locally dealing with global climate issues is through education (Kişoğlu, Gürbüz, Erkol and Akilli 2010; Gowda, Fox and Magelky 1997). This is so because education plays an important role in creating awareness among the young people (Taber and Taylor 2009). Unsurprisingly, many countries have begun including global warming topics into their school curricula. Thus, in our Malaysian context climate change is taught in Form Four biology courses as part of the *endangered ecosystems* curriculum. However, despite increasing attention to climate change in the curriculum, students continue to hold misconceptions about this topic (Rye, Rubba and Wiesenmayer 1997; Daniel, Stanisstreet and Boyes 2004; Shepardson, Niyogi, Choi and Charusombat 2009; Shepardson, Niyogi, Roychoudhury and Hirsch 2013). Students tend to conceptualize climate change differently from the scientists' view. Studies have shown that students hold misconceptions despite being instructed on a topic because of teaching methods and vagueness of textbook presentations (Storey 1992). The exam-oriented nature of science education also contributes to the production of misconceptions, as students prefer rote memorizing concept words rather than the understanding thereof (Storey 1991).

The present study was designed to test whether students, taught by means of a curriculum grounded in a constructivist epistemology and with materials adopted from sources such as the United Nations Framework Convention (1992) (experimental treatment) would lead to better understandings of climate change-related concepts among Malaysian high school students than the regular, state-mandated curriculum (control treatment).

Background: misconceptions related to climate change and pedagogies to address the misconceptions

In this section, we briefly review the literature on misconceptions related to the four areas addressed in the present study: global warming, greenhouse effect, ozone layer depletion, and acid rain.

Misconceptions about the greenhouse effect

In contrast to the scientific description of the greenhouse effect, many students believe that the earth is warming as a result of increased solar radiation entering the atmosphere through the ozone hole (e.g. Rebich and Gautier 2005). Some students understand the greenhouse effect as the trapping of solar energy by greenhouse gases or clouds. Many students also think that the greenhouse gases themselves are being trapped. This misunderstanding of the greenhouse effect may result in part from the direct analogy to a greenhouse, which maintains heat by preventing convection and by trapping warm air inside (Gautier, Deutsch and Rebich 2006). Such studies also indicate that students tend to be unaware of the natural greenhouse effect produced by atmospheric gases. The most common misconception is that human beings are destroying the ozone and that this destruction brings about the greenhouse effect. Andersson and Wallin (2000) report that students incorrectly suggest human activities to be the primary cause of the greenhouse effect. Some students do not know about the greenhouse effect (e.g. Pruneau, Moncton, Liboiron and Vrain 2001) or make no distinction between the greenhouse effect and global warming (e.g. Boyes et al. 1993). One study found reasonably high levels of knowledge in 11- to 17-year-old students (Fisher 1998). This study, which compared the understandings of Australian children with their peers in the United Kingdom, found that most students were able to identify carbon dioxide as a gas that contributed to the greenhouse effect but not the other gases, including methane. Australian students were also able to make connections between the felling of trees and the greenhouse effect. However, large gaps were identified in terms of understanding the phenomenon, especially when asked to scientifically explain the phenomena.

Misconceptions about global warming

A considerable number of studies exist concerning the misconceptions of students and their level of knowledge about global warming (Darçın, Bozkurt, Hamalosmanoglu and Kose 2006; Boyes and Stanisstreet 1992; 1994; Boyes, Stanisstreet and Daniel 2004; Bozkurt and Aydoğdu 2004; Khalid 2001; Andersson and Wallin 2000). One recent study examined Australian upper primary students' knowledge and understanding of global warming and the greenhouse effect and their willingness to act in ways that might reduce these phenomena (Skamp, Boyes and Stanisstreet 2007). Many of the younger students, in particular 11 and 12 year olds identified improving the water quality of the ocean, reducing street litter, and reduction of pesticide use as steps to be taken to mitigate global warming. There is an apparent confusion between general environmental issues and global warming. Other studies show that some students see the consequences of global warming as causing skin cancer (Boyes and Stanisstreet 1998; Pruneau, Gravel, Courque and Langis 2003); some students over-estimate current temperature increases (e.g., 11 °C over the past 10 years; 0.3 °C in reality) (Gowda, Fox and Magelky 1997); and yet other students see no immediate or future impact on society or humans (Pruneau et al. 2001; Pruneau et al. 2003). Students also believe that global warming and climate change cannot be stopped (Pruneau et al. 2001) or limiting the emission of carbon dioxide is a solution to the problem (Andersson and Wallin 2000). A study involving fifth-year biology student teachers showed that they (a) were under the impression that ozone layer depletion was the main cause of global warming and (b) assumed that greenhouse effect was completely an anthropogenic phenomenon rather than a naturally occurring process (Çimer and Ursava 2011).

Misconceptions about the ozone layer

As seen in other topics (e.g., acid rain, global warming), pupils in primary and secondary schools as well as university students have particular misconceptions associated with ozone layer depletion (Bahar, Bag and Bozkurt 2008). Many students believe that ozone layer depletion is a major cause for global warming and that the hole in the ozone layer allows a greater penetration of sunlight that results in raising the temperature of the earth (Rye, Rubba and Wiesenmayer 1997; Toili 2007). Such misconceptions are strongly held and resist change despite media publicity and despite inclusion of the issues in the formal curriculum (Jeffries, Stanisstreet and Boyes 2001). Students are reported to have flawed mental models that attribute increasing global temperature to increasing solar input through the ozone hole (e.g. Rebich and Gautier 2005). The results of the survey of first-year students in Australia also showed that a majority held two misconceptions: (a) the ozone hole resides over Australia and (b) ozone depletion is the major cause of Australia's high rate of skin cancer (Cordero 2001). A recent study in Turkey with 177 rural high school students showed that even though most of the students seemed well informed about the nature of the ozone layer, many held some misconceptions related to ozone layer damage, its causes, and its consequences (Pekel and Ozay 2005). Few students realized that gases released by volcanic eruption can reduce the concentration of stratospheric ozone, whereas many recognized that radioactivity, gases from the fridges and plastics, rainforest destruction, and acid rain could lead to reductions. Thus, many students thought that ozone depletion would exacerbate the greenhouse effect and as a consequence increase flooding and heart attacks, danger to marine organisms, unsafe water supplies, or air escaping to the space.

Misconceptions about acid rain

Conception and conceptual change studies have reported misconceptions about acid rain (Arslan et al. 2012; Khalid 2001). Thus, for example, pre-service elementary science teachers misunderstand that acid rain is formed when charcoal is burned and that acid rain damages some stone building more than others (Khalid 2001). Some pre-service teachers also believe that acid rain can be produced in nature (Khalid 2003). Other commonly identified misconceptions are that (a) acid rain leads to an increase in global warming, (b) helps some plants and animals to survive, (c) burns everything that it comes in contact with, (d) acid rain occurs because of greenhouse gases and ozone layer depletion, and (e) CO_2 is the main cause of acid rain (Arslan et al. 2012; Dove 1996). Despite the existence of misconceptions about acid rain, reports on efforts taken to improve this situation are still limited, though relevant pedagogical approaches have been developed.

Pedagogical approaches used to address the misconceptions related to climate change

Misconceptions tend to be associated with teaching approaches that are based on information transfer and the delivery of scientific content (Lord 1999). According to Lord, lecturing helps students get good grades, but it does not help eliminate their misconceptions. Lecturing methods, therefore, do not appear to have a real impact on student knowledge and their everyday practices in which such knowledge would be mobilized. In fact, Lord contends that traditional teaching methods may *increase* misconceptions among students. As one study showed, failing to take into account students' conceptions resulted in their difficulties to understand scientific concepts (Hunt and Minstrell 1997). There appears to be a connection between teaching method and correcting the misconceptions (Begquist and Heikkinen 1990). Successful teaching occurs when the students' misconceptions are eliminated and conceptual change takes place. In the context of climate change, instructional strategies such as the generative learning model and concept mapping were identified as strategies that could assist to restructure the alternative conception related to global warming and improve understanding (Rye et al. 1993). Similarly, Porter et al. (2012) suggested that effective instructional strategies – those that are based on a constructivist epistemology, involve cooperative learning, and emphasize student inquiry – promote learning. A socio-constructivist-based pedagogy and experiential learning process led to improved student conceptions among 14–16-year-old students (Pruneau et al. 2003).

Theoretical framework

This study is grounded in constructivist theory generally and in the conceptual change model specifically. The constructivist experience will lead the students through the stages of conceptual change and ultimately lead to conceptions that are closer to the scientifically accepted ones. From a constructivist perspective, the purpose of teaching is to encourage and support a change from misconceptions to scientifically acceptable conceptions and to avoid the development of misconceptions (Driver 1989; Hewson and Hewson 1988; Driver and Oldham 1986; Strike and Posner 1992). Conceptual change cannot be achieved by traditional didactic methodology aiming at information transmission but, because learners are seen as the agents in the reconstruction of their own ideas, only through an active approach (Tsaparlis and Papaphotis 2009). The conceptual change approach is now a widely accepted means for allowing students to learn scientific concepts (Piquette and Heikkinen 2005).

Posner at al. (1982) suggested that for conceptual change to occur: (a) students must be dissatisfied with existing conceptions before truly wanting to abandon them; (b) the new concepts must be intelligible and plausible to them; and (c) the new conception must be fruitful in the sense that students can apply these to new situations. In this study, the climate change activities were grounded in the conceptual change approach to constructivism. The climate change activities used five hands-on activities, all of which pertain to real-world issues. The activities were designed to provoke cognitive conflict when students, working in small groups, attempted to solve problems. During the activities the students learned through a process of constructing, interpreting, and modifying their own representations based on their experiences (Driver et al. 1994; Kearney2004) as well through interaction with peers and engaging in new ideas with the teacher (Solomon 1987).

A review of related literature on misconceptions about climate change indicates that it is imperative for teachers to employ appropriate and effective instructional strategies to encourage and support the transformation of existing misconceptions into scientifically more appropriate conceptions. Such instructional strategies grounded in constructivist perspectives frequently have been highlighted effective. This is particularly the case when the traditional conceptual change approaches that focused on individuals are situated in students' relations with others: a socio-constructivist approach to conceptual change (Duit et al. 1998; Pruneau et al. 2003).

Method

This study was designed to investigate the efficacy of a curriculum on aspects of climate change. A quasi-experimental design involving experimental and control groups with pre-test as covariate (Shadish, Cook and Campbell 2002) was used to test the effectiveness of climate change activities in remediating the misconceptions indentified by means of a pre-test. Using a treatment for the control group allows us to reduce the natural maturation effect as an alternative explanation of causation. Qualitative interviews were conducted with randomly selected students to deepen our understanding of the student understanding after the treatment.

Research participants

The sample for this study consisted of 73 Form Four science stream students in Malaysia. Students were between 16 and 17 years of age. For this group of students, biology is a compulsory subject. After completing Form Five, they will be tested on the acquisition of knowledge and skills concerning biology as part of the Malaysian Certificate of Education (Sijil Pelajaran Malaysia is the equivalent to the British O-level examination). Two intact classes from two different schools were randomly assigned to experimental and control treatments. The experimental group consisted of 35 students with 18 boys and 17 girls exposed to climate change activities implementing a conceptual change approach. The control group consisted of 38 students with 24 boys and 14 girls who were taught the same concepts concerning climate change. However, the control group used the existing activities that are suggested in the official state syllabus.

To minimize the effect of nested treatment conditions, we matched the participating schools and teachers on several variables. Both schools are fully government funded co-educational schools in the same district (suburb), with more or less the same number of students and teachers. In both schools, the generally middle-class student population predominately consists of Malays, followed by Chinese, Indian, and other ethnic origins. Both schools have basic amenities such as science labs and computer and Internet facilities. Both classes were taught by their regular biology teachers, who have similar teaching experiences (5–6 years) and who have completed their MEd degree with an emphasis in science education at the same university. The two teachers of the control group and experimental group were informed of the learning goals (lesson plans were prepared ahead) and of the lessons topics to be covered.

Treatments

We briefly describe the treatments that experimental and control group received. (Detailed lesson plans for both groups may be obtained from the first author.)

Experimental group

The experimental group was instructed using four foci: acid rain, greenhouse effect, global warming, and ozone layer depletion. Students were asked to perform the activities in groups of five followed by an in-group discussion. The entire set of activities was conducted over a five-week period (one activity per week). The activities included role-play, hands-on laboratories, and a video exploring the ozone layer. For instance, in Lesson 1 about acid rain, the teacher began the lesson by presenting information about acid rain and its effect. Students subsequently were divided into groups of 5 with each group taking up a different role, such as mangrove swamp, fish, man-made objects (buildings and statues), and humans. Students were given a set of questions to discuss in their groups concerning the specific role they had to play out. For the example, the mangrove swamp group was asked to discuss the environment: suitable pH-levels for sustaining life, common causes of decline in populations arising from the effects of acid rain on reproductive cycles, effects of acid rain on food, and the existence of the swamp as a human destination. After completing their in-group discussions, students presented the results of their discussions to the remainder of the class. At this time, peers and teacher asked more questions not previously covered. In this context, the constructivist basis of the curriculum is apparent. Thus, for example, the lesson is controlled and mediated by the learners. The tasks focused on the realistic approaches to solving real-world problems and the learning environment created a real-world circumstance (e.g. Roth and Barton 2004; Roth and Désautels 2004). Additionally, the activities provided encouraged regulation, awareness, and possibilities for the students to construct knowledge (Jonassen 1991).

Control group

The control group conducted activities on the same topic over a five-week period (one activity per week for 2 hours). These followed a traditional teacher-centered lecture format with students listening, discussing in groups and presentation of the outcome of discussion. The teacher began teaching the topic on the endangered ecosystems by providing the information about the activities that endangered the ecosystem such as deforestation and the adverse effects deforestation has on the climate and greenhouse gases. A more specific presentation of acid rain issues followed during the subtopic on air pollution. The students were lectured on the formation of acid rain and at the end of the lesson the students were required to identify the effects of acid rain on buildings, living things, and the environment.

For the purpose of illustrating the effect of acid rain the teacher demonstrated the activity "acids eating my nose." The topics of the greenhouse effect and the thinning of the ozone layer followed the subtopic of air pollution. During the teaching of this subtopic, detailed illustrations on the greenhouse gases and its effect were provided to the students. The teacher discussed the effects and causes of global warming and asked the students to work in small groups. In their groups, the students were asked to read the text from the textbook and discuss the issue among the peers. The presentation of the outcome of discussions and explanation from the teacher followed. After that, students answered the questions in the textbook. At the end of the lesson, the teacher drew the conclusions. The thinning of ozone layer was also taught using similar approach. The teacher began the discussion by explaining the formation of ozone layer and how the layer appears above the Arctic. This was followed by identifying the causes for the thinning of the ozone layer and discussing the impact of ozone depletion on humans and the ecosystem.

In the control group, the teacher controlled teaching and learning. Even though peer group discussions were observed, these, too, were dominated with the teacher: she instructed students to read the textbook for the purpose of achieving the objectives and goals of the lesson as stated in the curriculum specification. During the lessons, the reproduction of the knowledge was emphasized. Despite discussing the contemporary issues that impact the world, the learning context did not create a relevant real-world environment in the classroom possibly because of the clearly apparent exam orientation that the teacher displayed while delivering the concepts.

Instruments

The Atmosphere-Related Environmental Problem Diagnostic Test (AREPDiT)

The three-tiered 13-item Atmosphere-Related Environmental Problem Diagnostic Test (AREPDiT) adapted from Arslan, Cigdemoglu and Moseley (2012) was used in this study to measure understanding, obtain information about possible reasons for answers, and gather information about students' level of confidence (available from the first author upon request). Few studies used 3-tiered diagnostic tests in science education (Caleon and Subramaniam 2010; Eryilmaz and Surmeli 2002) and none of these focused on environmental issues. Three-tiered tests appear to be more valid and reliable for the assessment of achievement or misconception than 1-tiered tests (Pesman and Eryilmaz 2010). The first part of each item belongs to the *content* tier and consists of a multiple-choice question. The second tier is based on a *possible reason* for the answers given in the first tier with one blank choice to express any personal reason. A third, *confidence tier* is an indication of the strength of the respondents' conceptual understanding. The instrument includes questions that measure understanding related to global warming, greenhouse effect, ozone layer depletion, and acid rain. The following is an example of the types of question included in the AREPDiT:

1.1 The ozone layer

a. Protects the Earth from acid rain.
b. Filters the ultraviolet (UV) rays of the sun.
c. Helps to keep the earth's temperature stable to make it livable.

1.2 Which one of the following is the reason for your answer to the previous question?

a. The ozone layer absorbs the sun's ultraviolet (UV) rays, which is potentially damaging to life on the Earth.

b. The ozone layer prevents sunrays to exit from the atmosphere, consequently keeps it warm enough to live.

c. The ozone layer works as a kind of shield, so it does not let acid rain to reach the Earth's surface.

d. ………………………………………………………………………………

1.3 Are you sure about your answer given to the previous two questions?

a. Yes

b. No

Reported reliability and validity estimates

The Cronbach alpha reliability coefficient for the whole test was estimated to be 0.74 (Arslan et al. 2012). Senior experts established content and face validation. The AREPDiT items were scored based on student responses to all three tiers of items. If a student's response to the first tier and second tier were correct and the confidence was high, then the item was coded 1 (correct); otherwise it was coded as 0 (Pesman and Eryilmaz 2010). A moderate positive correlation between the participants' first and second tier scores and their certainty scores had been used as evidence for construct validity.

Pilot study for establishing reliability and validity in the Malaysian context

Prior to this research, a pilot study was conducted including 38 students of the same age group and at the same level of schooling. The main goal of the pilot study was to evaluate the reliability and validity of the effectiveness of a diagnostic instrument in terms of content coverage and language appropriateness for the Malaysian context. Five secondary school biology teachers with 5–10 years of teaching experience validated the content of the questions. The evaluators commented that the content of the instrument covered almost 95% of the syllabus and that it was reliable, accurate, and suitable to be used with Malaysian Form Four students. The language and terms used in the diagnostic instrument were identified as appropriate for the students to understand the intended meaning of each item. The Cronbach alpha values of the four subtests were α = .75 (global warming), .81 (greenhouse effect), .77 (ozone layer), and .74 (acid rain), suggesting "good" reliability of the instrument (Gay and Airasian 2003).

Interviews

Students from both experimental and control treatment groups were interviewed to investigate the persistence of misconceptions and the nature and quality of their (mis-) understandings following the instructional sequences. Ten students from each of the two groups were randomly selected. The interviews were conducted by the third author and lasted for about an hour. The interview questions asked were based on the questionnaire items. The questions focused on identifying students' understandings about climate change, greenhouse effect, global warming, ozone layer depletion, and acid rain. The following are examples of interview questions:

1. What do you understand about climate change/ global warming?
2. Can you give examples of the consequences that humans face due to global warming? Explain your answer.
3. Can you tell me what causes the hole in the ozone layer?
4. What comes to your mind, when you hear the term "acid rain"?
5. What causes acid rain?
6. Can you tell me what types of gases are involved?

Analyses

A quasi-experimental approach that randomly assigns whole classes to treatment and control is recommended for experimental research in school classrooms (Shadish, Cook and Campbell 2002). These authors suggest that using a control group is of minimal advantage unless pretests are used to improve internal and external validity of a study. Following the recommendations of these authors, we used the pretest as a covariate in an analysis of covariance (ANCOVA) design that had the same test as its outcome measure. Because four tests of understanding were used in this study, we employed a Bonferroni adjustment—$\alpha_{adj} = \alpha/n$, where n is the total number of tests conducted—to keep the alpha level for the total experiment at $\alpha_{exp} = .05$. The ANCOVA design requires that the null hypothesis of equality of regression—between covariate and dependent variable—be rejected. Thus, prior to testing the research hypotheses, tests were conducted to ascertain that the equality of regression slope assumption was not violated for each of the four tests.

Results

This study was designed as a test of the null hypothesis comparing student understanding of climate change-related concepts when taught using an experimental versus traditional curriculum. The quantitative results are elaborated with more detailed information gathered during post-treatment interviews.

The effect of climate change related teaching activities

The tests regression slopes for all four tests reported showed that the assumption of equality was not violated. We therefore proceeded to testing four null hypotheses using ANCOVA with pretest as a covariate. The students' understanding of climate change following an experimental curriculum does not differ from that following a regular curriculum as measured by the AREPDiT subtests related to (a) the greenhouse effect, (b) global warming, (c) ozone layer depletion, and (d) acid rain. To control experiment-wise error rates, Bonferroni adjustments were used to test each hypothesis at the corresponding $\alpha_{adj} = \alpha_{exp} /4$ levels (i.e., α_{adj} = .013, .0025, .00025).

The first hypothesis stated that there would be no difference in understanding of the greenhouse effect between experimental and control treatment groups as measured by the corresponding AREPDiT subtest. This hypothesis was rejected ($F(2, 70) = 6.74$, $p < .013$). The experimental treatment group ($M_{exp} = 1.51$, $SD_{exp} = 0.56$) outperformed the control group ($M_{cont} = 0.97$, $SD_{cont} = 0.55$), suggesting that they better understood the central concepts of this dimension of climate change.

The second hypothesis pertained to the equality of understanding following the two instructional methods relative to global warming. The null hypothesis was rejected ($F(2, 70) = 17.14$, $p < .00025$). Students in the experimental group exhibited better understanding of global warming concepts ($M_{exp} = 3.29$, $SD_{exp} = 0.86$) than their peers in the control group ($M_{cont} = 2.03$, $SD_{cont} = 1.15$).

The third hypothesis compared student understanding in experimental and control groups relative to the ozone layer depletion. The null hypothesis was rejected ($F(2, 70) = 19.38$, $p < .00025$). On average, students in the experimental group exhibited better understandings as measured by the AREPDiT subtest ($M_{exp} = 3.17$, $SD_{exp} = 0.82$) than the students of the control group ($M_{cont} = 1.84$, $SD_{cont} = 0.89$).

With respect to the understanding of acid rain concepts, the null hypothesis that students in the experimental group exhibit the same understanding following treatment as students in the control group was rejected ($F(2, 70) = 13.43$, $p < .00025$). The experimental group ($M_{exp} = 2.46$, $SD_{exp} = 0.85$) outperformed the control group ($M_{cont} = 1.68$, $SD_{cont} = 0.93$) on the understanding of acid rain concepts as measured by the related AREPDiT subtest.

To better understand the nature of these results, we calculated for each item the percentage of students with misconceptions as indicated by their AREPDiT item scores. Table 1 shows that on each item, the percentage of students in the experimental group holding misconceptions dropped between 31 and 52 percentage points. On the other hand, in the control group, the percentage point decrease ranged from 0 to 22; but on two items (#5, #7), the percentage of misconceptions increased slightly.

««««« Insert Table 1 about here »»»»»

Interviews

In this study, interviews were used with 10 randomly chosen students from each experimental and control group to investigate persistence/prevalence of misconceptions and the nature and quality of student understandings following the instructional sequences. Representative interview responses of students in the control group and experimental group were translated into English by the first author.

Control group

The ten students interviewed in the control group tended to exhibit misconceptions. They asserted that climate change is about change in weather because of an increase in carbon dioxide and that carbon dioxide is the only greenhouse gas. These students experienced difficulties explaining the link between greenhouse gases and climate change. The excerpts below are examples of the students' responses:

Student A: The weather actually is the climate, so, it is not same anymore like a few years back. It is getting hotter because so much heat in the atmosphere so, it is just too hot as a result of increased in carbon dioxide. Climate change happens because of the carbon dioxide released from the car and this gas trap the heat from atmosphere.

Student C: Not sure how greenhouse gases are related with climate change. I remember when we used to build the greenhouse the teacher used to mention something like it traps the heat to maintain the temperature of the greenhouse, but I am not very sure.

Misconceptions related to global warming, ozone layer depletion and acid rain also persisted among the interviewed control group students. For example, Student B attributed global warming to hot weather being trapped rather than to the fact that the atmosphere is heated by the absorption of long-wavelength light:

Student B: The hot weather that trapped in the atmosphere causes the temperature of the Earth to increase. This phenomenon is known as global warming and climate change. It affects people's health. Thinning of ozone layer happens due to CFC released from aerosol and acid rain, which is rain that is acidic. The atmosphere is polluted this causes the rain acidic.

The control group students also experienced difficulties in stating other consequences of global warming on health. Their responses indicate a general problem of scientifically understanding the relationship between global warming and contemporary global situation. The quotations below exemplify the students' lack of knowledge:

Student C: Mainly health related problem, such as skin cancer. This because increase when the temperature increases it is hot; we have drink more water to avoid.

Student D: Children are getting sick more often. Our resistance to diseases is decreasing.

Experimental group

The responses of seven experimental group students explicitly indicated that they had developed more suitable understandings of climate change, greenhouse gases, global warming, ozone layer depletion, and acid rain. However, misconceptions persisted in three of the 10 students interviewed. The following excerpts illustrate the responses of the students who have exhibited improved understanding:

Student E: Climate change means the divergence in earth's global climate with time. It refers the average state of the atmosphere over time scale changing.

Student F: Greenhouse gases are nitrogen oxide, water vapor, methane, sulfur dioxide and carbon dioxide. These gases trap the heat from the sun and not all the heat reflected back. Most of it retained in the atmosphere. This phenomenon causes the increase in the temperature. Actually, the greenhouse effect is important to keep the earth warm. However, what is happening now is there are more greenhouse gases that trapped more heat than required and this contribute to climate change.

These excerpts exemplify how the students from the experimental group explicitly differentiated between climate and weather, which we did not observe in the control group. The students from experimental group talked about multiple gases that contribute to the greenhouse effect, in contrast to the students from the control group who maintained that carbon dioxide is the only greenhouse gas. The students from experimental group were able to distinguish between the greenhouse effect and the function of greenhouse as human technology for growing plants, in contrast to the control group students, who generally did not make this distinction. The experimental group students tended to use a discourse in which the greenhouse effect is a naturally occurring essential phenomenon; however, its impact was said to intensify with various other greenhouse gases that are the result of human activities. Further evidence for the sophisticated discourse of the experimental group students can be gleaned from the following interview excerpts:

Student E: Global warming is a natural process. This is a process whereby some of the heat from the sun trapped at the atmosphere of the Earth for the purpose of keeping the Earth warm. The heat that is not trapped by the greenhouse gases will be reflected into space. At some point greenhouse gases also radiates heat in the form of infrared radiation. This also contributes to the warming of the global. This causes the climate to change.

Student G: Ozone layer protects us from direct sunlight, infrared radiation. It is made out of three oxygen atoms. When there are greenhouse gases, the oxygen atom will become radicals. In the form of radical the oxygen will react with the other greenhouse gases and this will create a hole in the layer.

The discourse displayed expresses the competence to scientifically describe global warming as a naturally occurring phenomenon and explain how greenhouse gases contribute to global warming. This discourse also suggests a thorough understanding of global warming as one of the causes of climate change, which contrasts the misconception often noted in the control group that global warming is climate change or vice versa. The experimental group students' were able to describe the chemical composition of the ozone layer and scientifically illustrate how the holes are formed. On the other hand, the misconception that CFC from aerosols is the cause for ozone layer depletion persisted in both groups.

Student G: The pH of normal rainwater is from 5.6 to 5.8. It is acidic when the pH less than 5. Acid rain mainly happens because of high concentration of pollutants in the atmosphere such as carbon monoxide, nitrogen oxide and sulfur dioxide. These substances combine with the rainwater (water vapor) to form nitric acid and sulfuric acid and forms acid rain.

Student E: Climate change and global warming have tremendous effects on everyday people's living. People's health is severely affected. Seawater is getting more and more and fishermen's incomes are affected. We also face other social problem such as frequent flooding extreme weather such heavy thunderstorm and lightening.

These interview excerpts exemplify the experimental group students' greater understanding when compared to the control group students. The control group students did not provide detailed illustrations in the way the experimental group students did. Rather, the control group students' discussions of the phenomena are indicative of a surface-level understanding. The experimental group students, on the other hand, exhibited more in-depth, sophisticated discussions and apparent understandings about global climate change.

Discussion and conclusions

This study was designed to investigate the impact of specially designed activities that implement constructivist principles fostering conceptual change on Malaysian Form Four students' understanding of climate change related concepts. The outcome of ANCOVA analysis and interview responses indicate that the experimental students exhibited significantly improved understandings and fewer misconceptions about global warming, greenhouse effects, acid rain, and ozone layer depletion. The climate change activities as used in this study provided a context for the students to learn while actively engaging in tasks with others rather than attending a teacher-centered course.

Given that the research design was based on groups matched on (a) cultural and socio-economic background, (b) teacher training and experiences, and (c) and curriculum contents, we propose that the significant differences in understandings and the reduction in misconceptions likely are due to the conceptual-change focused approach. For instance, when the students performed various roles during the activity on acid rain, we observed them in active engagement in the discussions on the impact of acid rain on their role as fish, manmade structure, people and mangrove swamp. We noted that suggestions and ideas that emerged during such discussions provided a context for the students to analyze their own existing knowledge. Any conflicting viewpoints became a ground for students themselves to pose additional questions. In the process of finding answers each group member was exposed to multiple angles on the same issues.

Consistent with findings of other studies that implemented constructivist teaching and learning (e.g., Porter, Weaver and Raptis 2012), our study provides evidence that students exposed to appropriate activities will undergo conceptual change. The climate change activities provided the ground for the students to learn and understand climate change related concepts. The effectiveness of the climate change activities was also evident from the interview responses of the students. Our probing revealed that misconceptions clearly and unequivocally persisted among students from the control group. On the contrary, only 3 of the 10 students from the experimental group exhibited misconceptions.

This study also confirms other research studies that reported little change in understanding following lecture-based approaches and even less understanding (perhaps more misconceptions) following the teacher-centered approach (Porter et al. 2012; Treagust et al. 2011). Future research might be conducted following work in mathematics education, which shows, with exacting detail, how specific hand-arm and rhythmic body movements translate into subsequently verbalized scientific talk about relevant phenomena (e.g. Roth 2011).

In this study, students who engaged in hands-on activities that also required them to work with their peers outperformed students who merely attended teacher-centered lessons. This finding is consistent with other studies investigating hands-on activities in the context of collaboration (e.g. Stohr-Hunt 1996; McConnell, Steer and Owens 2003). Why should there be differences given that in both settings, students were exposed to the same phenomena and concepts to describe and explain the former? Held and Hein (1963) conducted the first experimental demonstration about the differences between operating in and being visually exposed to some environment. Their study was conducted with kittens, where the active kittens pulled carts in which the passive kittens were placed (Held and Hein 1963). This study reported that kittens who moved about showed extraordinarily larger brain development than those kittens merely observing the world around them. Similar effects might be expected among human learners, who should experience more development when actively involved in activities (including speaking) rather than just observing (including listening). Recent neuroscientific studies are consistent with such expectations, for agents cannot perceive objects and movements unless they have previously operated upon or enacted them (Rizzolatti, Fogassi and Gallese 2003). The neurosciences predict that one cannot learn just by means of looking.

The climate change activities used in this study would be a replacement for the existing methods recommended by the Malaysian curriculum specification of biology Form Four (CDC 2006). In the context of Malaysia, various approaches have been suggested by the researchers to improve students understanding of climate change issues (UNESCO 2013; NASA 2013). When teachers are more concerned with completing the syllabus to prepare students for end-of-year examinations, anything that appears to go beyond the narrow confines of the textbook are rarely implemented. However, the climate change activities did not add to the already overwhelming curriculum as the activities were designed as an alternative to the existing curriculum. Future studies are suggested to investigate teacher and student experiences with respect to the workload when the constructivist student-centered activities replace teacher-oriented approaches.

Even though the quasi-experimental approach using an ANCOVA design can rule out many alternative hypotheses for explaining significant group differences and, thereby, contribute to increasing the external validity of a study, there are issues that this design cannot address (Shadish et al. 2002). Thus, for example, in this quasi-experimental design, the teacher variable is nested; it therefore cannot be ruled out that the teacher rather than the curriculum is the cause of the differences observed. Moreover, although the two schools are similar in their descriptive aspects—drawing students from the same ethnicities and socio-economic status—it cannot be ruled out that observed differences are due to the nested effects of school and the student population. Further studies are warranted to exclude the possibilities related to the nested effects.

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Table 1

Proportion of students with misconceptions

Alternative conceptions	Experimental group (%)			Control group (%)		
	Pre-test (%)	Post-test (%)	Differences	Pre-test (%)	Post-test (%)	Differences
Global Warming						
1. To define global warming	57	26	31	53	47	6
2. To explain the consequences of global warming	57	17	40	61	39	22
5. To explain which one is not effective solution for global warming	54	17	37	53	58	-5
6. To explain the way to decreases the global warming	57	11	46	53	53	0
Greenhouse effect						
3. To explain the greenhouse effect	63	23	40	68	53	15
4. To explain the effect of greenhouse effect	66	26	40	63	50	13
Ozone Layer Depletion						
7. To define OLD	63	26	37	61	63	-2
8. To explain the causes of OLD	63	26	37	55	47	8
9. To explain the consequences of ozone layer	57	14	43	61	58	3
10. To reduce OLD	54	17	37	54	46	8
Acid Rain						
11. To describe AR	69	17	52	58	45	13
12. To explain the consequences of AR	63	23	40	55	45	10
13. To explain the precautions against AR	66	14	52	58	42	16