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Informed-Decision Regarding Global Warming and Climate Change Among High School Students in the United Kingdom

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Abstract Global warming and climate change are serious issues facing humanity at present and education needs to focus on including informed-decision in classroom practices. The conceptual framework used in this study has provided interconnections that influence beliefs and understandings in providing a knowledge base for making "informed-decision" among high school students. This study was conducted in three year 9 classes in two high schools in the UK and among 65 students. An inquiry intervention model was developed using the 5E instructional model (Engage, Explore, Explain, Elaborate, and Evaluate) to identify beliefs and understanding and to strengthen students' knowledge base. This study used a design-based research setting and utilised a mixed methodology. The Wilcoxon signed-rank tests were computed to examine the pre-post-difference among questionnaire items, and structural equation modelling (SEM) was utilised to explore the relationship between belief, understanding, and intention. Data analysis of the intervention revealed that students developed a strong understanding of the causes and effects of global warming. There is evidence that students used that knowledge to "inform-decision" in relation to global warming and climate change. Promoting informed decision-making through science teaching can encourage responsible action in the future. The real gap identified in this study is that the regular school curriculum does not engage socio-scientific issues in the real world and has no opportunity to organise an inquiry-based instructional sequence for informed decision-making.

Résumé Le réchauffement climatique et le changement climatique sont des problèmes graves auxquels l'humanité est actuellement confrontée, de sorte que l'éducation doit se concentrer sur l'inclusion de la prise de décision éclairée dans les pratiques en classe. Le cadre conceptuel utilisé dans cette étude présente des

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interconnexions qui influencent les croyances et les compréhensions en fournissant une base de connaissances pour la prise de « décisions éclairées » chez les élèves du secondaire. Cette étude a été menée dans trois classes de 9e année dans deux écoles secondaires du Royaume-Uni et auprès de 65 élèves. Un modèle d'intervention par l'enquête a été élaboré en utilisant le modèle pédagogique 5E (Engager, Explorer, Expliquer, Élaborer et Évaluer) pour déterminer les croyances et la compréhension et pour renforcer la base de connaissances des élèves. Cette étude a utilisé un cadre de recherche axé sur la conception et a utilisé une méthodologie mixte. Les tests des rangs signés de Wilcoxon ont été calculés pour examiner la différence avant / après entre les éléments du questionnaire et la modélisation d'équations structurelles (MES) a été utilisée pour explorer la relation entre la croyance, la compréhension et l'intention. L'analyse des données de l'intervention a révélé que les étudiants ont développé une solide compréhension des causes et des effets du réchauffement climatique. Les données probantes indiquent que les étudiants ont utilisé ces connaissances pour « éclairer les décisions » concernant le réchauffement climatique et le changement climatique. La promotion d'une prise de décision éclairée par l'enseignement des sciences peut encourager une action responsable à l'avenir. La véritable lacune recensée dans cette étude est que le programme scolaire ordinaire n'aborde pas les questions socioscientifiques dans le monde réel et n'a pas la possibilité d'organiser une séquence pédagogique fondée sur l'enquête pour une prise de décision éclairée.

Keywords Global warming · Climate change · Informed-decision

Introduction

Climate change is one of the most pressing issues at all governmental levels across the world, threatening the global economy as well as the very existence of the planet. Increased greenhouse gas emissions, global warming, and climatic changes are serious environmental issues and require responsible action by all nations and individuals (IPCC, 2014). While immediate mitigating effects can be achieved through government legislation to change industry behaviour, permanent change to human impact on climate change requires individual, as well as collective, actions. Decisions and actions taken by individuals can have impacts similar to those achieved when a factory undertakes technological advances to reduce greenhouse gas emissions.

Education needs to change to focus on twenty-first century issues and on every aspect of daily life to secure the future of the planet (UNESCO, 2003). A number of pedagogical and learning requirements follow from this. School pupils who will face the effects of climate change need to participate in dialogue and decision-making around contemporary issues (Barab et al., 2005). Teaching and learning should engage with the practice of constructing, testing, refining, and justifying evidence-based scientific explanations to make authentic connections between environmental issues and students' daily lives (Braaten and Windschitl, 2011). Teachers should encourage students to reflect on their own scientific problem-solving process (Wilson et al., 2012). Cognitive and motivational aspects in classrooms could impact on willingness to take action to reduce greenhouse gas emissions (Sinatra et al., 2012). Environmental education particularly on global warming and climate change provide opportunity for inquiry, when it is inclusive of and led by young people. This would populate next generation of leaders who are not avoiding climate change in their policies, decisions, and actions (Cutter-Mackenzie & Roussel, 2019).

Environmental education should be an integral part of high school education. In Agenda 21 (United Nations, 1992), an agreement was made between nations regarding the contribution of environmental education to the defence of the environment. Further, the social character of environmental issues links them to the everyday habits of individuals, as well as to the future of the planet. Social standpoints and worldviews on climate change among people would challenge resilience for conceptualising interactions and climate change education (Lawless, 2018). The solutions to major environmental problems are not easy and require major changes in lifestyle, and unprecedented international agreement is required for cooperation in educating people about environmental issues.

A scientifically literate public could improve the quality of public decision-making and action. Greater familiarity with the nature and findings of science will also help individuals to question pseudo-scientific information (Royal Society, 1985). Sadler et al. (2004) asked high school students to demonstrate their understanding of global warming as presented in two media articles. The results showed that only 47% of students were able to understand and explain the use of data in the articles. Fifty-three percent of students were deemed to have a very basic understanding of the data. Other studies (Detterman & Sternberg, 1993; Haskell, 2001) also point to students lacking skills in converting their scientific understanding into informed decision-making about a scientific issue. Furthermore, issues like greenhouse gas emissions and global warming are not included in teaching and learning programs and teachers tend to avoid teaching these topics (Kurup et al., 2015).

Overall aim of this article is to link the informed decision-making with related and contributing factors and identifying roles of each aspects in taking decisions. Scientific literacy generated from a knowledge base, beliefs, and understandings are the aspects contributing and they play vital roles (Wu & Tsai, 2011). Climate change education needs a dynamic focus with student-centred teaching and learning as well as inclusion of personally relevant, challenging, and meaningful contexts (Monroe et al., 2019).

Conceptual Framework

Climate change is a risk made by humans and raises questions about contemporary lifestyles, such as material consumption and energy use. Therefore, it is important that students gain better understandings of the issue (Pilot & Bulte, 2006). Beliefs and understandings constitute clarity of scientific discourse and assessment of scientific information. Beliefs regarding environmental issues can influence a wide range of attitudes concerning the environment and the consequences of human activities. Beliefs also lead to the understanding of a person being a part of the natural environment (Schultz, 2001; Heimlich & Ardoin, 2008). The interpretation of a socio-scientific issue like climate change not only requires background science knowledge but also positively held beliefs about the reality and impacts of the issue (Thomm & Bromme, 2012).

Interdisciplinary approaches (Johnson & Adams, 2011) to democratic informed decision-making align with the Next Generation Science Standards (NGSS Lead States, 2013) focus on integrating divergent thinking. Such approaches involve different ways of thinking, solving problems, and communicating. Students learn to use a range of technologies to plan, analyse, evaluate, and present their work. They learn valuable reasoning and thinking skills that are essential for functioning both inside and outside the school environment, and about the creative design principles and processes involved. Use of the Internet means that the nature of learning today is interactive, where schools take the initiative in designing active learning that emphasises the interaction rather than just the content (Anderson, 2004).

It is important to empower students to deal responsibly with issues associated with climate change, and education should address understanding as well as societal implications of democratic informed-decisions and actions (Schreiner et al., 2005). Likewise, Perkins (2014) uses the concept of "lifeworthy learning" to discuss an approach to educating young people for a changing world. If students are provided with authentic scenarios in which decision-making involves considerations of different viewpoints and realistic estimates of risk, they will look for relevant evidence to make rational decisions (Kurup et al., 2015). In reality students should be capable of using their knowledge, not just in a scientific context but also for societal and environmental needs (Fernández-Manzanal et al., 2007), and Slaughter's (1996) categories for future planning scenarios of *predict*, *prefer*, *possible*, *promise*, and *precedent* proved a useful framework in civic democratic decision-making based on the knowledge base.

Providing a variety of scenarios and roles regarding this socio-scientific issue should lead to sustainable literacy and enhance public understanding of science (Colucci-Gray et al., 2006). The construction of an argument and counter-argument are essential aspects of higher order thinking, providing an arena that demands the use of the skills of analysis, synthesis, and evaluation. Developing such skills requires not only opportunities to practice their use but also knowledge of metalinguistic features of their essential elements and ability to resolve key differences (Osborne & Patterson, 2011).

Solutions to complex issues like climate change require political, economic, cultural, social, and individual decisions and actions. School science programs should allow participation in society and this would have potential for lifelong participation in socio-scientific issues. In this process, teachers and students are required to extend their knowledge of science procedures and connect it to democratic civic decision-making(Fensham, 2015; Fensham, 2016). The knowledge gained from practical life-oriented situations provides students with confidence and competence to function effectively as informed citizens (Ryder, 2001). An education program targeting socio-scientific issues should encourage students to actively participate in societal issues by selecting suitable contexts that are related to the daily lives of students (Liu et al., 2011; Dede, 2009, 2013). Hence, high school students need to participate in issues associated with climate change where decisions and actions require significant lifestyle changes. This would provide uninterrupted lifelong learning related to what is important in day-to-day life and help students cope with changes in their daily lives (Roth & Lee, 2004).

In the conceptual framework of this study, education is considered as the key to reduce greenhouse gas emissions and an important aspect of scientific literacy and public understanding of science. A knowledge base is provided to the students by an intervention using the 5E instructional model (Bybee, 1997, 2015). The 5E instructional model of teaching and learning focuses on inquiry-based science teaching and learning through a constructivist approach. This model enables student learning from their prior knowledge to achieve an ownership of the knowledge in a learning journey of a five-phasecycle—engage phase to evaluate phase. The *Engage* phase identifies prior knowledge including alternative conceptions; *Explore* phase provides authentic learning situations in a challenging way, and hands on activities; *Explain* phase encourages using correct scientific understanding to explain science phenomena; *Elaborate* phase enables using concepts in new situations to gain ownership of the knowledge; and *Evaluate* phase generates an overall picture of learning outcomes.

Overall, the conceptual framework describes interconnections and influence of beliefs and understandings in providing a knowledge base that would make informed-decision. Figure 1 outlines the conceptual framework.

Research Questions

The present study reports the influence of an intervention programme among year 9 students in two schools in the UK on their beliefs, understanding, and intention for action to reduce global warming. The aim is to

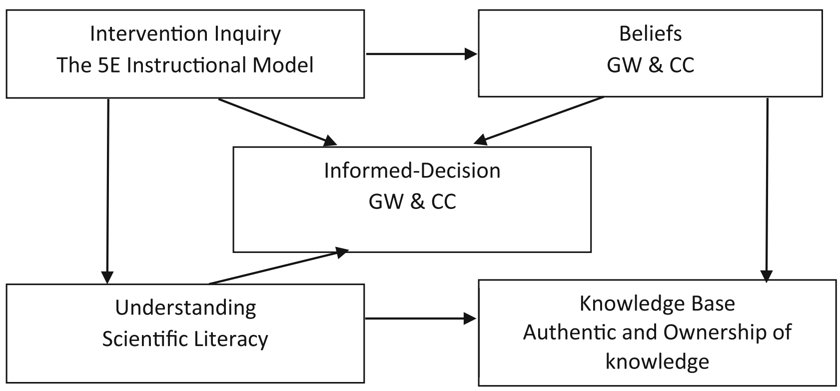

Fig. 1 Conceptual framework

provide a knowledge base (knowledge with beliefs and understanding) regarding the issues of global warming and climate change and test how it is influencing informed-decision among high school children.

The study centred on two primary research questions:

1. How does a 5E instructional model-based unit of global warming and climate change intervention enhance beliefs about, and understanding of, the key science concepts of global warming in terms of a strong knowledge base?
2. How do these enhanced beliefs and understanding and knowledge base influence informed-decision regarding scenarios of global warming and climate change?

Methods

This study was conducted in a design-based research setting (Design-Based Research Collective, 2003) and used a systematic yet flexible methodology and contexts in a real-world setting covering characteristics of design-based research (Feng & Hannafin, 2005). The study utilised a mixed methodology and collected quantitative and qualitative data, and data sets were crosschecked and triangulated. This enabled the formulation of assertions and conclusions that are based on a variety of sources and evidence (Tashakkori & Teddlie, 2003; Nolen & Talbert, 2011). All attempts were made to legitimate the use of multiple approaches in answering research questions by using a variety of data sources such as quantitative data (form pre- and post-questionnaire), qualitative data from observations by researchers, teachers and pre-service teachers, and focus group interviews (Johnson & Onwuegbuzie, 2004). The structural equation model (SEM) is used to find the interrelationship between beliefs, understandings, and intentions for action using the questionnaire data. The methodology used in this study is also consistent with similar research conducted in the area of applying knowledge for informed decision-making regarding socio-scientific issues (Sadler & Zeidler, 2005a; Sadler & Zeidler, 2005b; Zeidler et al., 2005).

The study was conducted in the following four steps to suit the methodology:

Step 1. Professional development for participating teachers and pre-service teachers regarding administering questionnaire, ethical aspects, and finalising the intervention lessons sequence based on the 5E instructional model. This half-day professional development provided teachers with a clear framework of the scope of the research.

Step 2. Administering the pre-test questionnaire one week before the start of the intervention and gathering quantitative data about beliefs, understandings, and intentions regarding global warming and climate change.

Step 3. Two weeks of intervention lessons. Data-gathering based on observations, focus group interviews (qualitative data).

Step 4. Administering post-test questionnaire two months after the intervention to quantitatively identify changes in beliefs, understanding, and intentions.

Participants, Instruments, and Study Workflow

The participants in this study were three year 9 classes (65 students aged 13–14) from two high schools in the UK. This sample is selected as a sample and aims to achieve representation of year 9 students in the UK following the guidelines for mixed methods sampling (Teddlie & Yu, 2007; Kemper et al., 2003). Ethics clearance was obtained from the Ethics Committee of the Institute of Education, University College, London.

Three teachers and two pre-service teachers were involved in the study. They were provided with professional development to include ten lessons over two weeks covering informed decision-making regarding global warming and climate change in their lessons, subject to the needs of the schools and curriculum requirements (Gayford, 2002). The professional development was conducted in one of the schools over three hours, covering ethical issues (volunteer participation, consent letters, and anonymity in sample collection), administering of questionnaires, familiarisation with and finalisation of the ten-lesson sequence based on the 5E instructional model, data collection, and focus group interviews.

The main researcher of this study was present in 25 out of a total of 30 sessions, and fully involved in all activities during these sessions as a participant observer. A log record was created with summaries of all lessons including casual conversations during the lessons. Samples of students' work were collected with permission. Semi-structured focus group interviews were conducted by the researcher during the lessons as most of the time students were working in groups. Focus group interviews were conducted in groups during the group work to generate clarity of their beliefs and understandings including some of the representations.

The questionnaire used is standardised for this type of study and has five parts (Kurup et al., 2005).

i. Identifying concerns and beliefs about the issue, including the relative importance of the issue compared to other issues in daily life.
ii. Probing students' understanding of the greenhouse effect and global warming.
iii. Asking about actions taken regarding ten easy ways of reducing greenhouse gas emissions.
iv. Probing students' reactions to a proposal to reduce car use.
v. Dealing with students' sources of information about the greenhouse effect, and expectations about government actions.

In this study, four parts of the questionnaire covering beliefs, understandings, and intentions for actions were used before and after the intervention. The questionnaire adapted for this study had Part A to rank relative importance of seven issues including greenhouse effect and global warming, Part B five questions (A1 to 5) regarding beliefs about global warming on a five-point Likert scale, Part C questions (B1 and 2) to probe understanding about the GHE based on a written explanation of a partial diagram to show the GHE and the knowledge of greenhouse cases, and Part D (C1 to 10 and D) regarding intentions to act regarding 10 common practices whether they are already doing, consider doing and intend to do in future, and a decision based on their future car use. The details of each variable used are described in the "Process and results" section.

Analysis of data was conducted qualitatively and quantitatively, so that to arrive at an authentic conclusion.

Various statistical analyses were conducted like Wilcoxon signed-rank test (to find significance of intervention in building understanding of the science behind climate change and to identify the significance of identifying greenhouse gases after intervention). Finally, the structural equation model (SEM) was used to formulate interrelationships between beliefs, understanding, and intentions. Specific details of analysis are explained with the results. Scenarios related to global warming and climate change that are familiar, connected to daily life, and concern everyone were used to identify how students use knowledge to make decisions. Several studies, like this study based on teaching and learning activities, used informed-decision connected to environmental issues (Grace & Ratcliffe, 2002; Jiménez-Aleixandre, 2002; Liu et al., 2011; Yang & Anderson, 2003).

The Learning Journey

The intervention lessons were based on the 5E instructional model (Bybee, 1997). The 5E model was found to be effective in the curriculum development process and producing units of work on a variety of topics in science. Primary Connections (Australian Academy of Science, 2005) used the 5E model in their units and found that teachers could use the model effectively to enhance their confidence and competence in teaching science as well as students enjoying learning science (Hackling & Prain, 2005). The 5E model being an activity-based model of teaching and learning science has the potential to develop twenty-first century skills such as adaptability, complex communications skills, non-routine problem solving, self-management/self-development, and system thinking (Bybee, 2009, 2010; NRC, 2006).

Beliefs (**B**) and understandings (**U**) were targeted at the *Engage*, *Explore*, and *Explain* stages of the 5E sequence; informed decision-making (**ID**) was targeted at the *Elaborate* and *Evaluate* stages.

The 5E instructional model intervention lessons were designed to obtain a learning journey starting with students' prior knowledge, and proceeding to what was finally achieved in terms of changes in beliefs, conceptual understanding, and their position towards issues associated with GW and CC. Every student had a 40-page notebook as their journal. Students were encouraged to provide a variety of representations including graphical representations of carbon dioxide emissions over the last century, comparing global average temperatures, flow charts, concept maps, and posters of facts and figures.

Intervention lessons were formulated by researchers', pre-service teachers', and teachers' participation, and the finalised version of the program is provided in Table 1.

Process and Results

Ranking of Global Warming and Climate Change Before and After the Intervention

Students were asked to rank the importance of seven issues in a questionnaire given two weeks before and four weeks after the intervention. The seven issues were economic issues and poverty; global warming and climate change; increasing crime; terrorism; health and diseases like AIDS; family breakdown; and increasing drug use. Before the intervention, the mean rank students gave GW and

Table 1 Global warming and climate change intervention unit at a glance

Phase	Lesson	Description and target
Engage	1. What you believe and know about global warming and climate change	Represent, discuss, describe, flowchart, concept map to identify what students believe and know about global warming and climate change (**B** and **U**)
Explore	2. Cars, farms, factories, and forest 3. Global warming 4. Climate change 5. Issues of global warming and climate change	Identify and make connections between sources of greenhouse gases and human activities (**B** and **U**) How increased concentrations of greenhouse gases accelerates global warming (**U**) How global warming influences climate changes/IPCC main arguments (**B** and **U**) Generating a scenario of global warming and climate change (**U**)
Explain	6. Facts and figures	Explain causes, effects, and mechanism of global warming and difference between ozone layer depletion and the greenhouse effect (**U**)
Elaborate	7. Group research 8. Group decisions 9. Group presentations	Identifying some issues causing global warming and science behind these issues (**ID**) Finding solutions and possible actions regarding global warming (**ID**) Presenting different scenarios with description and action to reduce global warming (**ID**)
Evaluate	10. Final class presentation of the decision	Generating an action plan based on group discussions and deliberations as a whole class (**ID**)

CC was 5.32, indicating a relatively low level of importance. However, after the intervention, the mean ranking changed to 1.8, indicating there is a considerable shift in their ranking. It is also interesting to note that one could argue that economic issues and poverty are pre-cursors to action on GW and CC; hence, it is more important. When students think GW and CC gains in importance after the intervention, it might be that it's more prevalent in their thinking rather than its importance. The real problem with this question is that all the factors are interconnected, and intervention provided a knowledge base to think about the reality and effects of GW and CC.

Engage Phase—Beliefs and Understandings About GW and CC

There were two schools and three classes of year 9's participated in this study. The following sequence structure was followed to indicate the two schools and three classes involved. School A, class A as (AA); school B, class A as (BA); and school B, class B as (BB). The focus of first lesson (Engage) was to find out the prior knowledge regarding the greenhouse effect, global warming, and climate change. The students had completed the questionnaire a week before this lesson. The teacher gave an introduction about the topic of global warming and showed a couple of concept cartoons; one of which was a polar bear leaving a place without any ice. These cartoons were shown to generate thinking about the topic and further discussions.

After being introduced to the class by the teacher, the researcher briefly described the unit of work and what was expected of students. The questions set for students included their beliefs and prior knowledge, what they believe and wanted to know, how their knowledge was useful in daily life, how to solve this issue, and what they believed they could do to contribute. Figures 2 and 3 are selected as samples from all 65 students and are representative of all samples examined (names shown in the figures and not real names).

These samples demonstrate students' knowledge of sources of emissions and some mention of plausible actions to reduce global warming. However, the explanations are vague, demonstrating rudimentary and incomplete knowledge, including confusion with ozone layer depletion. Students were asked about sources of their information regarding global warming. Most of them revealed that they get views from the media and friends. More than 20% of students confused the global warming with ozone layer depletion, which is consistent with previous research (Boyes et al., 1999; Rye & Rubba, 1998; Christidou et al., 1997; Dove, 1996; Kurup et al., 2005). Table 2 provides different aspects of representations of beliefs and prior knowledge of global warming and climate change from all students.

Students in general believe that global warming is a serious environmental issue; however, about 80% do not have sufficient knowledge to explain the basic science behind global warming and climate change, as shown in the following statements:

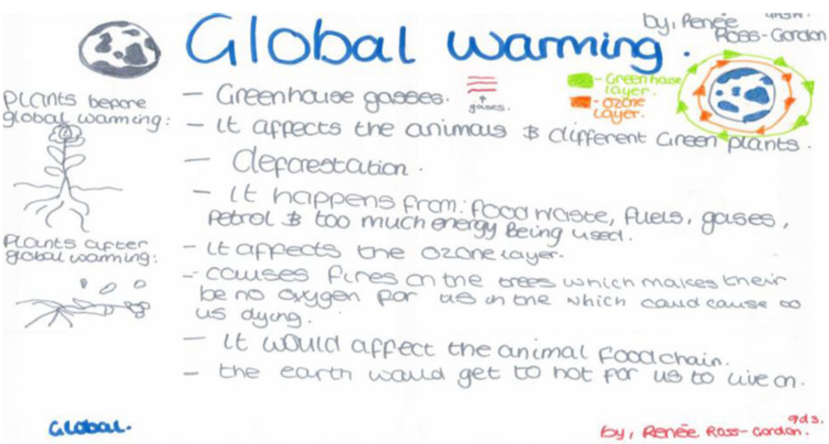

Fig. 2 Sample representation of beliefs and prior knowledge of global warming (AA)

Fig. 3 Sample representation of beliefs and prior knowledge of global warming (BA)

Student YY; School AA: “It’s Carbon the pollution, yes I agree it is going to be terribly hot, but very, very cold now, why is this miss!?”

Student XY School BA: “Ummm the pole is going to be a desert soon!” and “I don’t know whether it is a real thing there is warming now, can’t you see the snow the ice! … it’s too cold, now warm!, nonsense global warming”

These conversations indicate students’ confusion about the reality of global warming and climate change, and their genuine curiosity about its importance.

Explore Phase

This phase consists of four lessons providing hands-on activities that challenge students’ existing beliefs and understanding regarding global warming and climate change and aims to increase students’ understanding of scientific concepts associated with global warming. During Lesson 2 of this phase, students form groups and consider the inside of a car on a hot day compared to the outside temperature (“Yeah the car is getting sun rays and they hot up and hot up, if the windows are closed they will trap this hot, sometimes it can be terribly hot, yeah like the diagram in the earth”). They also discussed actual greenhouses on farms. Few students had seen an actual greenhouse and they explained the concept to others (“You know it is that cloth like thing on top of vegetables they maintain hot and it is green you know… that is why greenhouse”). The teacher and the researcher moved around the groups, clarifying their diagrams and explaining the mechanism of the greenhouse effect.

Students were struggling to connect the idea of how switching on a light increases global warming, so teachers and the researcher helped students to think about how electricity is generated and the consequences

Table 2 Details of representations of students’ beliefs and prior knowledge regarding global warming and climate change ($n = 65$)

No.	Aspects of representations indicating students’ beliefs and prior knowledge regarding GW and CC	% of responses
1	Flowcharts/concept maps/explanations demonstrating knowledge of sources of emissions. Mention plausible actions to reduce global warming	18.46
2	Partially completed flowcharts/concept maps/explanations with relevant key words	50.75
3	Concept maps with vague ideas of global warming with confusion of ozone layer depletion	21.54
4	Vague flowcharts/concept maps/explanations with rudimentary and incomplete knowledge	9.25

of doing so. Students were later provided with a flow chart connecting ideas of energy consumption, burning fossil fuels, CO_2 generation, and enhanced global warming.

Explain Phase

In this stage, teacher explained greenhouse effect, GW, and how that will lead to GW and students used correct scientific understanding to explain science phenomena. The main focus was explaining the difference between ozone layer depletion and the causes, effects, and mechanism of the greenhouse effect, which was a major misconception identified during the engage phase. Class discussions and teacher explanations provided students with correct scientific understanding of the causes, effects, and mechanism of the greenhouse effect. The main concepts emphasised were the natural greenhouse effect, enhanced greenhouse effect, greenhouse gases, how they are produced by human activities, and how greenhouse effect leads to GW and CC. Students were provided with 15 concepts and facts about GW and CC and in groups they discussed these science concepts and pasted in their journal. Students were enthusiastic and interested in learning more about increasing amounts of greenhouse gases causing global warming. The comparison of graphs of carbon dioxide increase and increase in average global temperature gave students an insight into the issue of how will increase in greenhouse gases contribute to GW.

Questionnaire Data Before and After Study Regarding Beliefs and Understanding of Global Warming and Climate Change

The variables used for beliefs, understandings, and intentions to act in the questionnaire are described in Table 3.

Student beliefs about the reality of global warming and actions they believed needed to be taken were studied before and after the intervention. Before the intervention, the mean was 3.48 for all the questions A21 to A25, and after it was 1.74 (towards agree or strongly agree as 1 strongly agree and 5 strongly disagree), demonstrating students had major changes in their beliefs regarding this issue and realise the importance of commitments and actions by everyone.

Student understanding about global warming was studied before and after the intervention based on their diagrammatic representations and explanations from the questionnaire. The full range of responses was read and reread to identify common elements and based on these elements criteria for levels were formulated. Level 1 represents the highest level of understanding and level 5 represents the lowest level. Before the intervention, students had a minimal understanding or misconceptions (mean level 4.35), after intervention provided a very good understanding (mean level 2.6). This is consistent with observations made during the *Engage* phase to identify their prior knowledge. Figure 4 will explain the details of five levels of understandings.

Identifying Gases Associated with the GHE

The greenhouse gases in the Earth's atmosphere include CO_2, CH_4, H_2O, N_2O, O_3, and CFCs. The students' responses also included non-greenhouse atmospheric gases like O_2 and N_2, and gases that are essentially absent (only present in extremely small concentrations) from the Earth's atmosphere like CO and H_2.

There were significant changes in identifying correct GHE gases before and after the interventions. Before the intervention, some of the students couldn't identify a single GHE gas (mean 0.51) whereas they could identify two to three gases after the intervention (mean 2.31). Non-greenhouse gases like O_2 and N_2, CO, and H_2 were identified before the intervention as greenhouse gases. It is also interesting to note before the intervention few students identified some non-greenhouse gases as greenhouse gases (mean 0.14); however, after the intervention, no student identified any non-greenhouse gases as greenhouse gases. The

Table 3 Description of variables used the questionnaire

Factors	Questionnaire items and descriptions	
Belief	A21	Effect of GW
	A22	Change in CC
	A23	Influence of personal actions
	A24	Influence of Governmental actions
	A25	Influence of Polices and laws
Understanding	B1	Minimal to Excellent Understanding
	B2	Identifying correctly GHE gases
Intention (action)	Practical_var (sum of C1-C10)	Consider, already and not interested in doing ten widely accepted actions to reduce GW
	C1	Walk, cycle, use transport
	C2	Use fluorescent globes
	C3	Reduce hot water use
	C4	Insulate homes
	C5	Use solar systems
	C6	Buy energy efficient cars
	C7	Conserve and plant tress
	C8	Switch off lights when not used
	C9	Buy energy rated appliances
	C10	Use manual devises instead of electrical
	D1	Decision on restricting car use

(Questionnaire has four sections A, B, C, and D, section A covers Beliefs, B covers Understandings, and C and D cover Intentions to action)

Wilcoxon signed-rank test was performed to compare if there is any difference in the identification of GHE gases before and after the intervention. The result showed the difference is significant with $p < 0.001$. In terms of the understanding aspect, we performed the Wilcoxon signed-rank test to check the difference before and after the intervention. The result showed there is significant difference with $p < 0.001$. Overall students' achievements after the intervention based on qualitative and quantitative evidence are the following. They can:

1. Explain global warming and climate change in terms of causes, effect, and mechanism (between levels 2 and 3)
2. Identify greenhouse gases and sources of greenhouse gases (could identify two or three greenhouse gases)
3. Understand the impact of human activities in contributing to the GW and CC

Elaborate and Evaluate Phases

During the Elaborate phase, students were asked to produce a flow chart to link certain activities with its effect on global warming and climate change. The majority of students could easily identify that planting trees will absorb carbon dioxide for photosynthesis and deforestation can reduce this absorption and raise carbon dioxide levels in the atmosphere. Students identified alternative sources of energy and that using public transport reduce carbon dioxide emissions, whereas farming and driving cars enhance carbon dioxide levels.

Level 1. The mechanism of the GHE was explained fully and correctly, and represented accurately in a diagram.

At Level 1, students stated that: 1.Sunlight passes through the atmosphere; 2.Most solar radiation is absorbed by the Earth's surface and warms it; 3. Some solar radiation is reflected back to space by the Earth and the atmosphere; 4. Infra-red radiation is emitted from the Earth's surface; 5. Some infra-red radiation is absorbed by greenhouse gases; 6. The effect is to warm the surface of the Earth and the lower atmosphere; 7. The natural GHE is due to the presence of naturally occurring greenhouse gases which trap some of the infra-red radiation in the atmosphere; 8.This effect causes the Earth to be warmer than it would be otherwise; 9. Increasing concentrations of several gases like CO_2, CH_4, N_2O, CFCs, O_3, and water vapour (identified at least three gases) enhance the natural GHE.

Level 2. The mechanism of the GHE was represented accurately in the diagram; however, the explanation of the mechanism was not complete. Students did not differentiate between the natural and enhanced GHE.

At Level 2, students stated that: 1.Sunlight passes through the atmosphere; 2. Most solar radiation is absorbed by the Earth's surface and warms it; 3. Some solar radiation is reflected back to space by the Earth and the atmosphere; 4. Infra-red radiation is emitted from the Earth's surface; 5. Some infra-red radiation is absorbed by greenhouse gases; 6. and identified at least two gases that cause global warming.

Level 3. The diagrammatic representations and explanation of the mechanism of the GHE were not complete; however, students did understand that CO_2 was involved in trapping emitted radiations and causing global warming

At Level 3, students stated that: 1. Sunlight passes through the atmosphere; 2. Most solar radiation is absorbed by the Earth's surface and warms it; 3. The Earth emits radiations that are completely absorbed in the atmosphere; 4. CO_2 absorbs radiation in the atmosphere and causes global warming; 5. but were not aware that some solar radiation is reflected back to space from the Earth and the atmosphere.

Level 4. Confused ozone layer depletion with the GHE

At Level 4, students stated that: 1. Production of gases like CFCs and CO_2 cause holes to form in the ozone layer; 2. The holes in the ozone layer allow UV radiation to pass through the atmosphere; 3. The increased concentration of UV radiation is causing global warming.

Level 5. Minimal understanding of the GHE

At Level 5, students provided little accurate information and the following are the main general observations: 1. Diagrams were inaccurate; 2. Explanations were incomplete and not scientifically correct regarding global warming; 3. Many of these students stated that pollution is causing global warming.

Fig. 4 Five levels of students' understanding of the GW and CC

Working in groups, students debated the pros and cons of reducing greenhouse gas emissions from burning fossil fuels, before coming up with policies for a new Energy White Paper. Groups were allocated different roles in relation to energy policy: government ministers; Department of Energy; Department of Transport; conservation group; oil lobby; car manufacturers' association; and concerned citizens (Simonneaux, 2001). All groups researched their priorities based on their allocated responsibilities, before presenting their ideas to the government, which came up with a final list of policies to be included in the White Paper. In all final policies, fossil fuel use, electricity use, and renewable energy were included. All policies outlined some actions required such as reduction targets and fines. Some examples of energy policies appear in Figs. 5 and 6.

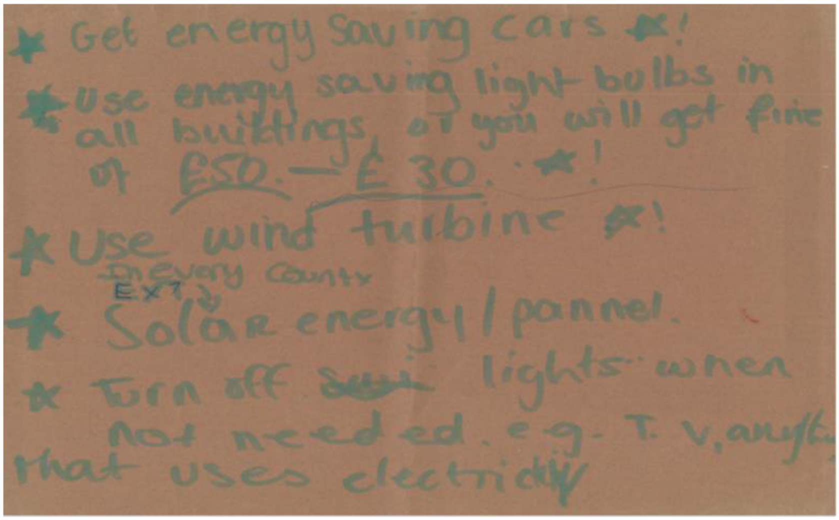

Fig. 5 Example energy policies

Questionnaire Data Before and After Study Regarding Intentions for Action

The data was analysed using SPSS statistical software (version 23.0) and Smart PLS (version 2.0 M3) (Smart PLS, Hamburg, Germany). The Wilcoxon signed-rank tests were then computed to examine the pre-post-difference among questionnaire items. Structural equation modelling (SEM) was employed to explore the relationship between belief, understanding, and intention. The obtained model was tested and modified using the PLS-PM approach. A p value less than 0.1 was considered statistically significant. SEM can be viewed as a combination of factor analysis and multiple regression including two parts: a measurement model relating the measurement variables (MVs) to their own latent variable (LV, the unmeasurable variable) and a structural model relating some LVs to other LVs. In this study, an exploratory factor analysis (EFA, principal component analysis with varimax rotation) was first used to explore the latent

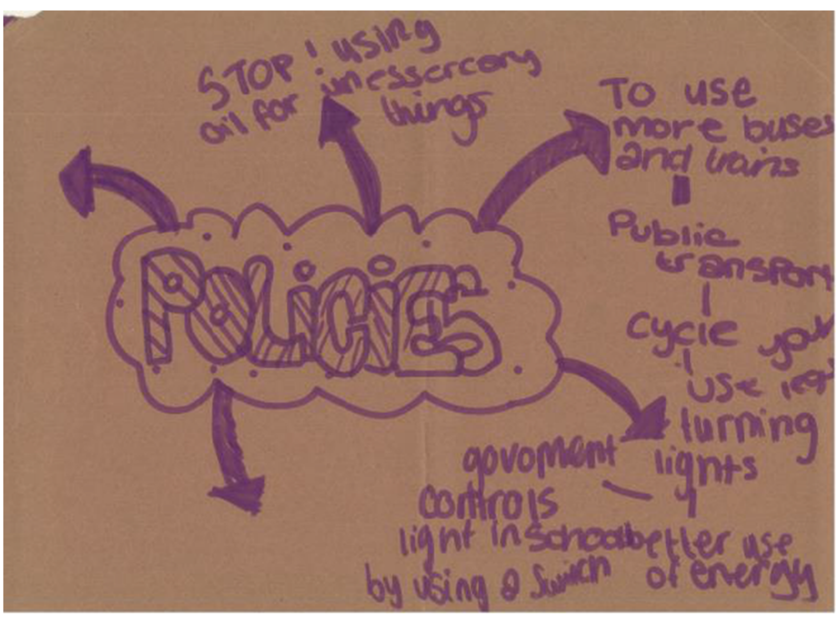

Fig. 6 Example energy policies

structure of the risk-factor variables for pre- and post-questionnaire, respectively; then, an initial SEM was constructed based on the results of the EFA. The latent structures used are of the questionnaire items pre- and post-intervention. EFA was used to extract latent factors from pre- and post-intervention questionnaire items. Bartlett's test of sphericity showed factor analyses may be useful with pre- and post-intervention questionnaire items (both $p < 0.05$). However, pre-intervention questionnaire data did not have a reasonable factor structure compared to post-items. So, in the following structural equation analysis, the factor structure found from post-intervention data will be used. Table 4 presents results of the analysis.

Complex Relationship Between the Proportion of MDR-TB and Risk Factors

Based on the results of the EFA, we constructed an initial model with questionnaire items using factors from Table 3 to formulate Fig. 7. Based on the iterative PLS-PM procedure and the practical meanings of variables, the modified model depicted in Fig. 7 included path coefficients of the structure model. Table 5 presents the evaluation of the measurement model, which shows that all factor loadings were higher than 0.7, the CR for each LV was above 0.7, and the AVE was always greater than 0.5. Therefore, the measurement models were considered acceptable for evaluation of the structural model.

In the modified PLS-PM(Fig. 8), the remaining variables had a substantial relationship with their respective dependent variables. All of the path coefficients, interpreted as standardised beta coefficients, were statistically significant ($p \leq 0.10$) except for the path from "Belief_Post" to "Understanding_Post". Nevertheless, this path met the evaluation criteria and was retained. The "Understanding_Post" factor had the largest effect, with a standardised path coefficient of 0.429 to "Intention_Post". Additionally, the "Belief_Post", "Belief_Pre", and "Understanding_Pre" factors had positive relationships with "Understanding_Post" with standard path coefficients of 0.216, 0.264, and 0.195, respectively. Finally, the "Belief_Pre" factor had a relationship with "Understanding_Pre" factor with standardised path coefficients of 0.352, and "Understanding_Pre" factor had a relationship with "Intention_Pre" factor with standardised path coefficients of 0.286.

The analysis-based SEM model provides the relationship of beliefs and understandings pre- and post-scenarios of the interventions and their interrelationships. It is clearly established that intervention provided students with beliefs and understandings that made them capable of making informed-decisions. Combin-

Table 4 Factor loadings from principal component factor analysis with varimax rotation: eigenvalues and percentages of variance for the post-questionnaire items

Item		Factor loading	
	Belief	Understanding	Intention
A21p	*0.85*	0.11	0.05
A22p	*0.83*	−0.04	0.16
A23p	*0.66*	0.36	−0.19
A24p	*0.86*	−0.05	−0.03
A25p	*0.88*	0.00	0.04
B1p	0.07	*0.60*	0.54
B2p	0.04	*− 0.85*	0.07
b4p	0.10	*0.82*	0.26
Practical_Varp	0.15	0.23	*0.66*
Dp	−0.11	−0.06	*0.80*
Eigenvalue	3.52	2.17	1.17
% of variance	35.27%	21.67%	11.72%

Practical_Varp is based on combined value of C1 to 10 to generate one value for Intentions

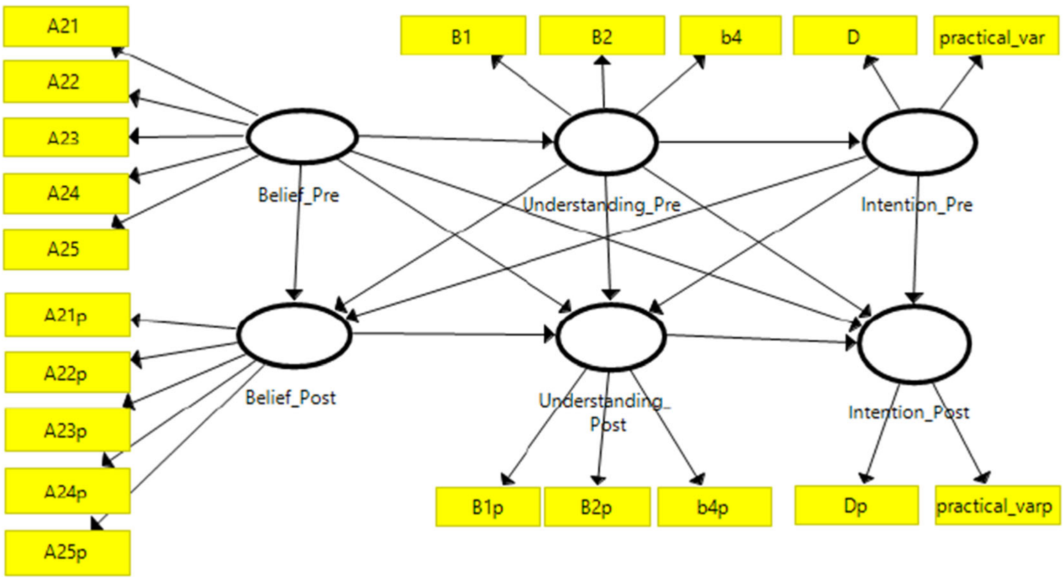

Fig. 7 Initial model with questionnaire items factors

ing qualitative and quantitative aspects from this intervention, the results indicate that intervention has provided adequate scientific understanding to interpret the issue and take appropriate actions. It is evident from the Elaborate and Evaluate phases that they use science concepts for their positions on issues and scenarios provided to them.

Table 5 Evaluation of the measurements of beliefs, understandings, and Intentions

Variables		Pre (median (IQR))	Post (median (IQR))	*p*
Belief	A21	2 (2)	2 (1)	<0.001
	A22	2 (0)	2 (1)	<0.001
	A23	4 (1)	2 (1)	<0.001
	A24	2 (1)	2 (1)	0.011
	A25	2 (1)	2 (1)	<0.001
	Sum of A21 to A25	28 (6)	10 (4.5)	<0.001
Understanding	B1	5 (1)	3 (1)	<0.001
Identifying gases	B2	0 (1)	2 (1)	<0.001
Intention (action)	C1	2 (2)	1 (1)	<0.001
	C2	2 (1)	1 (1)	<0.001
	C3	2 (1)	2 (1)	<0.001
	C4	2 (0)	2 (1)	<0.001
	C5	2 (1)	2 (1)	<0.001
	C6	2 (1)	1 (1)	<0.001
	C7	2 (1)	2 (1)	<0.001
	C8	2 (1)	1 (1)	0.041
	C9	2 (2)	1 (1)	<0.001
	C10	2 (2)	1 (0)	<0.001
	D	4 (2)	3 (1)	<0.001

Wilcoxon signed-rank test

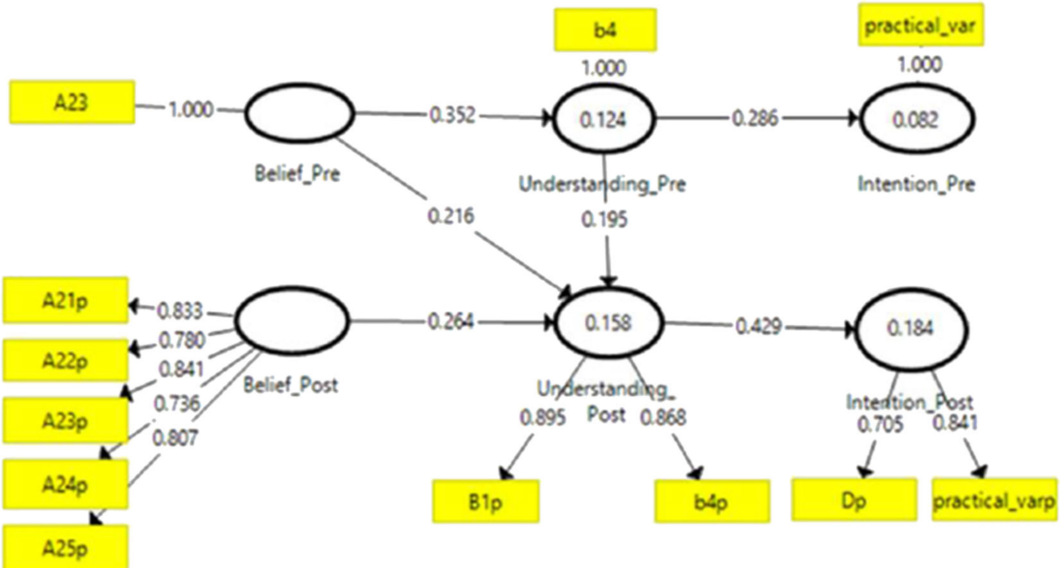

Fig. 8 Modified model with questionnaire items factors

Linking Beliefs and Understandings to Informed-decision and Success of Intervention

The 5E instructional model lessons provided students with an opportunity to use the knowledge they gained from the Engage, Explore, and Explain stages in making decisions associated with scenarios of GW during the Elaborate and Evaluate stages. Table 5 describes the key aspects identified before and after intervention from various data sources and assertions made.

The intervention influenced students' beliefs regarding scientific realities and issues associated with global warming. The main difference in their understanding after the intervention was that they have a better

Table 6 Key aspects of beliefs, understanding, and informed decision-making before and after the intervention

Aspect (stages in 5E model)	Before intervention	After intervention
Belief (Engage)	• Global warming one among many concerning issues facing humanity at present • Global warming is real and affecting our climate, but we don't know how or why • Energy use, car use, factories etc., produce gas pollution which is causing global warming • It is difficult to solve this issue	• Global warming a very serious issue facing humanity at present • Individual action is important and reducing global warming, everyone has a role to play • Decisions and actions are needed from all levels (governments to personal level)
Understanding (Explore and Explain)	• Minimal understanding of the causes, effects, and mechanism of global warming • Could not identify greenhouse gases or how they contribute to global warming • Impacts of human actions in terms of increased greenhouse gas emissions and enhanced global warming	• Very good understanding of the causes, effects, and mechanism of global warming • Could identify greenhouse gases, including sources and increased concentrations • Explain the impacts of human actions and enhanced global warming leading to climate change
Informed decision-making (Elaborate and Evaluate)	• Not very sure about what they could do to reduce global warming • Opposed to the use of cars	• Confident in making informed-decisions to reduce global warming • Had very strong reasons for their intentions and could explain why they took such a stand

understanding of the causes, effects, and mechanism of global warming and can identify the greenhouse gases and their sources. After the intervention, students had confidence in making informed-decisions with correct scientific explanations (Table 6).

Conclusions

Climate science requires clarity, coherence, and relevance in order to connect with citizens and their decisions on energy, food, water supply, and sustainability. Evidence-based and citizen participatory policy formulation is necessary given the varying state of knowledge, interests, values, and needs of society (Rapley et al., 2014). Classroom teaching of science should consider students' real-world experience of environmental issues, providing opportunity for students to use informed decision-making about issues such as energy use (Tsurusaki et al., 2013). Decision-making and policy formulation based on classroom deliberations can empower students in societal commitments and social justice (Dimick, 2012). These processes connect to the real use of science in daily life and probe engagement in science (Feinstein, 2011). Much science teaching and learning in the classroom is formal and textual, and hence disconnected from the real world. Promoting responsible socio-scientific decision-making through contextual teaching about the science behind global warming and climate change can influence responsible actions by future citizens (Herman, 2015).

The 5E instructional model unit of work based on a real-world socio-scientific issue like global warming provides students with skills such as justification of claims based on evidence. Being an activity-based model of teaching and learning science, the 5E model has the potential to develop twenty-first century skills such as adaptability, complex communications skills, non-routine problem-solving, self-management/self-development, and system thinking (Bybee, 2009; Bybee, 2010; National Research Council, 2006). They are taught to test the credibility of claims based on evidence and use their science knowledge in justifications (Sandoval and Çam, 2011). Overall engagement in such units can provide students with the ability to cultivate the knowledge and skills needed to participate in scientific argumentation and evidence-based informed decision-making(Sampson et al., 2011). Students' confident beliefs and understanding of climate science affirm the utility of knowledge in framing polices and evidence-based decision-making (Manz, 2012). There is a gap as the normal school curriculum does not engage science in the real world and pre-service teachers are also not getting an opportunity to organise an inquiry-based instructional sequence to teach in school-filled placements (Gunckel, 2013). Probably intergenerational (students, teachers, and parents) learning together on these issues could influence worldview and concerns and in turn lead to collective action (Lawson et al., 2019).

Use of the 5E instructional model by teachers and pre-service teachers can change the classroom environment; helping students to become scientifically literate citizens and make informed-decisions regarding their health, wellbeing, and environment (Gunckel, 2011). Bridging this gap needs a deliberate effort from all angles, such as school curriculum, teacher preparations, and overall education policies. An integrated project on socioscientific issues focusing informed decision-making could be possible within the existing structure with a team involvement of teachers from different disciplines (Kurup et al., 2015). Scientific literacy influences understanding of science and would contribute to collective decisions. A simple thing to do is make connections to everyday life in communicating science and provide opportunity for evidence-based decision-making in classrooms (Niebert et al., 2012). What is learned at school and information from other sources influences beliefs and understandings about global warming and climate change, and this influences intentions to act to reduce greenhouse gas emissions and the impact and importance of the knowledge base. The knowledge action gap in intentions to act regarding the issue would influence collective actions at all levels in daily lives for informed-decision(Kollmuss & Agyeman, 2002).

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