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# Preparing Adolescents for the Uncertain Future: Concepts, Tools and Strategies for Teaching Anthropogenic Environmental Change

**Xi Xiang [1,*] and Michael E Meadows [1,2,3]**

[1] School of Geographic Sciences, East China Normal University, Shanghai 200241, China; michael.meadows@uct.ac.za
[2] Department of Environmental and Geographical Science, University of Cape Town, Rondebosch 7701, South Africa
[3] College of Geography and Environmental Sciences, Zhejiang Normal University, Jinhua 321004, China
* Correspondence: xxiang@geo.ecnu.edu.cn

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**Abstract:** Humankind is increasingly being challenged by anthropogenic environmental changes and society needs to be better equipped with knowledge, skills and values to adapt to these changes. This poses new challenges for school education. We propose a framework towards future-oriented education by addressing three issues: a) How can the school curriculum be reframed to take account of anthropogenic environmental changes? b) What difficulties do students encounter when learning about these changes? c) What learning tools and pedagogical strategies are best suited to effectively and efficiently teach about environmental changes? An example is provided, whereby secondary school students engage with the topic of deforestation using geospatial technology. This study informs curriculum makers and instructors in providing education that enhances adolescents' understanding of the uncertain world and increases their ability to be proactive, rather than merely responding to change.

**Keywords:** human-induced change; future-oriented education; Spatial-temporal thinking; geospatial technology; secondary school geography

## 1. Introduction

The earth's environment has changed since its very beginning in a complex and even turbulent manner, which is a natural part of the earth system. However, the exponential rise in human population accompanied by a huge increase in natural resources exploitation and evolving technology have combined to result in a significant human footprint on the planet [1]. In recent years global environmental changes have become more obvious, and there is strong evidence that many of these changes have been induced by human activity [2]. Globally, concentrations of carbon dioxide and other greenhouse gases continue to rise through the use of fossil fuels and deforestation of natural vegetation [3]. For example, widespread clearance of tropical rain forest, most notably in the Amazon basin [4] testifies to the magnitude of human impact that has deleterious consequences on a global scale [5]. Although indisputable evidence has emerged that humans have brought about significant impacts on climate and other elements of the environment, human causes and contributions to these changes are more irregular and often poorly understood [6].

Various measures have been implemented to mitigate the negative impacts of environmental decline; for instance, building large-scale infrastructure projects, or managing disasters like wildfires. Leveraging education is an indispensable element of global response to environmental change and an essential pathway of achieving sustainable development [7,8], since societies and individuals must be

empowered by knowledge, skills and awareness to deal flexibly with such a change. Research has shown that improved education significantly reduces vulnerability to climate-related disasters and strengthens the adaptive capacity in developing countries [9]. However, our understanding remains incomplete about how school education contributes to student learning of the changing environment and their ability to take actions towards a preferable future.

Globally, we face a world of complexity, uncertainty, fierce competition and rapid technological change, and this presents challenges for adolescents and leads to the rise of future-oriented education [10]. Organization of Economic Co-operation and Development (2018) has highlighted the importance of educating adolescents for the unknown future and towards a more meaningful personal life [11], although there is much debate as to how to achieve this goal. On one hand, the skills-driven approach is regarded as essential to helping students survive in such a world, which emphasizes twenty-first century proficiencies such as critical and creative thinking, and problem solving [12]. So-called 'powerful knowledge' is a concept that has attracted increasing attention in recent years, and one that offers alternative possibilities for enabling adolescents to thrive in their world and to shape their future. Grounded in disciplinary knowledge, this concept provides conceptual frameworks for students to learn effectively the underlying mechanisms of the physical and human world, for example cause and effect about how the world works [13]. In our opinion, the skills-based and powerful knowledge approaches are not incompatible but rather interdependent and mutually beneficial. The acquisition of skills can support the attainment of powerful knowledge and stimulate intellectual growth, while powerful knowledge offers the context where technological and other skills can be practiced and enhanced.

The nature and scale of human impact is such that we have arguably moved the earth into a new geological epoch; and that this has necessitated a paradigm shift within the education community [14]. The essential questions in considering educating about environmental change in the context of formal education are: "what to teach?", "how to teach" and "what have students learnt?" Therefore, the research problem for this study focuses on the ways that school education can be reconstructed to respond to this shift in terms of school curriculum, student learning and pedagogy. The key questions to be addressed include: a) What kind of school curriculum is relevant to the study of anthropogenic environmental changes at secondary level? b) What difficulties do students encounter when learning about these changes and how they improve their conceptual thinking? c) What learning tools and pedagogical strategies are suited to effectively teach about environmental changes?

## 2. Responding to Environmental Changes through Education

### *2.1. Constructing a Framework of Teaching Environmental Change*

We formulate here a conceptual framework as a tool for teaching environmental change with four stages (Figure 1). First, it is necessary to set the learning goal and the context from which this goal rises. Environmental change, represented with an orange rectangle, offers a suitable contextual framework for educating for the future, since teaching and learning about these changes incorporates the study of ideas as to their future trends. In our framework, environmental change is a major focus, and learning skills related to changes are reinforced in the classroom through school education. The net result is that students gain knowledge, skills and values relating to sustainability, which is an example of powerful knowledge for a sustainable future, represented with a blue rectangle.

Achieving such a learning goal demands new ways of thinking about alternative futures and what can be done to change them. The second stage is to specify the learning outcomes as "systematic environmental thinking". Based on prior research on systems thinking in the context of environmental change [15,16], three thinking skills are involved (i.e., identifying processes of the components within a system, analyzing dynamic relationships between components, and predicting future events based on past and present interactions). The learning outcomes serve as a guideline for assessing student learning about anthropogenic environmental change. In the third stage, three key aspects to teach

environmental change in formal education proposed in the Introduction section are illustrated with three components in the arrow flow chart: curriculum, cognition and pedagogy. Lastly, as the abilities in solving environmental problems caused by human activities are enhanced through spatial perspectives unique to the discipline of geography [8], designing a curriculum, learning experience and pedagogy for environmental change would benefit from incorporating concepts, tools and strategies in the geography domain. A total of 12 elements are categorized in four rectangles under each component and are elaborated one by one in the following sections.

Moreover, the learning outcome of the framework can be used as a basis for developing an instrument to evaluate the level of thinking related to environmental change. We propose this framework may also guide the design of educational interventions to develop systematic environmental thinking in secondary school students.

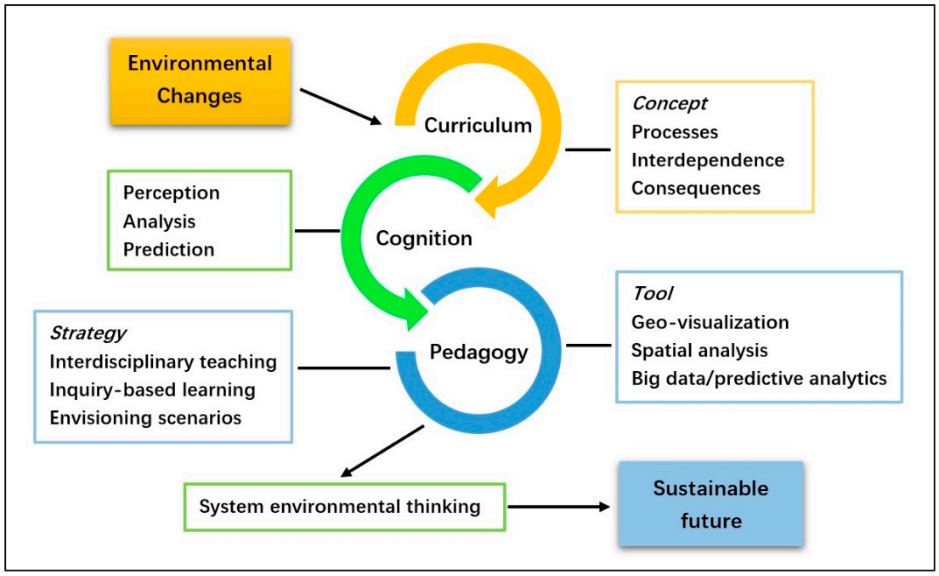



**Figure 1.** A conceptual framework for teaching environmental change.

## *2.2. Elements of the Framework Under Each Component*

### 2.2.1. The School Curriculum Response as a Context

Considering the increasingly dominant role of human activities in the global environment [5], we argue that the major environmental challenges, brought about by rising levels of consumption, and restructuring of economies and technologies, must be better represented in the formal education. Among all the school subjects, geography has a distinct advantage in developing students' understanding of environmental changes that occur at scales ranging from the local to the global [8]. The geography syllabus plays an important guiding role in equipping students with knowledge, skills and conceptual thinking that enables them to adapt to environmental changes. While the very concept of 'change' has emerged as key in the formulation of the school curriculum, its wider potential in educating for sustainable citizens has not yet been fully realized.

Accordingly, we review geography syllabi used in four countries where educating for the uncertain future receives greater attention, including the United States, England, Australia and Singapore, to identify core themes associated with anthropogenic environmental change at the secondary level (relating to 13-18 years old) (Table 1). The first theme, labeled as "processes of changes", requires students to "understand how sequences of events and activities in the physical and human worlds are part of our dynamic planet and changing world" [17]. The second theme, "interdependence", promotes in-depth understanding on how human actions modify the physical environment by exploring the inter-relationships and interconnections at all scales [18,19], with a particular attention

to explaining in which ways technology has expanded the scale of human modifications. The third theme, "consequences for people and environment", involves analysis of the positive and negative consequences of humans changing the physical environment. This theme consists of two layers that are "imagining how human-induced changes in one place can affect the physical environment in other places" [19] and "predicting changes in the future and identifying what would be needed to achieve preferred and more sustainable futures" [20]. The three themes formulate the backbones of studying anthropogenic environmental changes in secondary geography and lead to educational practice that deals explicitly with the interdependency of humans and environments.

**Table 1.** Core themes associated with the concept of "change" within geography syllabi [17–20].

| Theme | Description |
| --- | --- |
| Processes of changes | • Understand how sequences of events and activities in the physical and human worlds are part of our dynamic planet and changing world. |
| Interdependence | • Explore the inter-relationships and interconnections between physical features and human activities at all scales. |
| Consequences for people and environment | • Imagine how human-induced changes in one place can affect the physical environment in other places.<br>• Predict changes in the future and identifying what would be needed to achieve preferred and more sustainable futures. |

#### 2.2.2. Student Learning Grounded in Spatial-Temporal Cognition

In order to be capable of seeing more clearly what can be done differently at the local as well as global scale in the future, students need first to develop conceptual thinking around environmental change from a foundation based soundly on their existing knowledge and skills. Learning these changes involve three cognitive processes, namely perception, analysis and prediction. Perceiving environmental changes requires a cognitive reconstruction of the physical and human processes that occur over time. Small-scale empirical evidence has shown that secondary students have problems in processing information related to changes, for instance, describing changes in property, representing changes and visualizing move-related changes [16]. Because of their young age and limited life experiences, the time scale that the students can perceive is necessarily often very short [21]. Therefore, they frequently find it challenging to imagine things that occurred in the past [22], let alone making connections between the past and present.

Environmental changes comprise sets of cause-and-effect interconnections that can operate between and within places. Therefore, analyzing environmental changes involves initially identifying the nature of the connections and then relating the cause to the effect. Secondary school learners have experienced the difficulty in explaining changes in physical features that are associated with human activities [23]. It seems likely that limited reasoning abilities inhibit their understanding of inter-relationships between factors and determination of the causes and consequences of change [24]. Besides, the ability of the learners to analyze complex processes of changes may also be influenced by factors, such as preconceptions about variation in environmental changes [25], or knowledge of the relative contribution of anthropogenic forcing [26]. Nevertheless, there is a paucity of research on whether students can predict environmental change-related trends. Moreover, further research is needed that explores student response to other types of anthropogenic environmental changes, including, for example, urbanization, food security risk and deforestation.

#### 2.2.3. Geospatial Technology Supporting Innovative Pedagogy

What kind of learning tools can be considered to help resolve students' learning difficulties that students encounter when studying environmental changes? Geospatial technology offers perspectives to identify patterns and trends of environmental changes that cannot be unnoticed easily [26]. Although fieldwork is one of the best ways of illustrating the connections that make the observed system work, the emerging geospatial technology enables innovative pedagogy to integrate future education in

schools even without a hands-on field visit. We list three types of geospatial tools that have different demands of cognitive complexity and then analyze their advantages and disadvantages in terms of teaching environmental changes (Table 2).

**Table 2.** Evaluation of geospatial tools for teaching environmental change.

| Type | Example | Level of difficulty | Advantage | Disadvantage |
|---|---|---|---|---|
| Geo-visualization | Remote sensing Photography | Easy | Strong visualization ability to display changes | Low resolution |
| Spatial analysis | Geographic information systems (GIS) | Moderate | Strong analytical capabilities to identify causes of changes and model their consequences | Complex procedures to perform |
| Big data and predictive analytics | Tools such as Google Earth Engine, Global Forest Watch, Surging Seas | Challenging | Being able to make projections of future outcomes | Lack of availability of learning tools |

The first type of tool is geo-visualization, which involves remote sensing, such as *Google Earth* (https://www.google.com/earth/), and photographic or video technology, such as a webcam. A series of time-sequenced images provided by the tools allow students to visualize how the details of geographic features, such as their color, shape, size, texture and orientation, change over time [26]. However, the problem of using geo-visualization is that students may have difficulty in interpreting images with low resolution, particularly when recognizing the changing features and patterns. The second type of tool, Geographic Information Systems (GIS), has strong capabilities to analyze and synthesize spatial information. Student users can identify causes of changes by correlating different layers and model potential consequences of changes using the buffer function. However, there are numerous operational procedures to undergo when performing spatial analysis, so it would be difficult for secondary school students to manipulate this tool without effective tutoring.

The third type of tool, big data tools with real-time data collected by sensors, enable processing of huge volumes of data very quickly, establish correlations between datasets and provide accurate real-time analytics [27]. This kind of technology updates data-based perspectives to generate insights into environmental changes based on which proactive actions or precautions can be taken [28]. By way of example, tools such as Google Earth Engine (https://earthengine.google.com/), Global Forest Watch (https://www.globalforestwatch.org/) and Surging Seas (https://sealevel.climatecentral.org/), can be harnessed in the classroom for students to predict future outcomes of environmental changes like scientists. For instance, the interactive maps and data in Global Forest Watch make it possible to track the forest cover, deforestation and forest fire in any specific region across years or decades, thus offering students learning opportunities for estimating general forest trends. Although there are multiple big data tools available online for scientific research, very few of them incorporate teaching practice that supports student learning towards predicting future outcomes.

The features of geospatial technology are such that it cultivates learning processes for exploring and interpreting evidence of the changing world. For example, webcam technologies can be used to identify and make sense of changes in physical geography [22]. Empirical studies have demonstrated how temporal sequences of satellite images, available for example through Google Earth, and GIS can be utilized to significantly improve students' ability to recognize and analyze changes in land use, climate change and coastal processes [16,26,29]. However, little is known about how geospatial technology engages students to solve complex problems associated with environmental changes. In addition, empirical evidence concerning the effectiveness of such a visualization tool on students' ability to make predictions of these changes is still lacking.

#### 2.2.4. Instructional Strategy Scaffolding Thinking about Changes

We introduce three pedagogical strategies that can be employed to assist teaching of environmental changes when students interact with geospatial technology. Interdisciplinary teaching through integrating geography and history is a valuable means of dealing with learning difficulties that relate

to the perception of changes in a specific location. Capturing historical texts, either descriptions or photographs of places, helps students compare how the environment in the old days is different from oral history, the stories of ordinary people who experienced historical phenomena, and reveals changes in the landscape or what plant and animal species occurred in particular places over time [30]. Educators may support learning of the environment at specific historical periods by having students collect and analyze oral histories, for example from their grandparents or older residents in the local community. The indirect experience of the past that students obtain from these personal oral history projects enables them to connect the experiences and attitudes of older people with their own personal stories [31].

It is worth noting that merely applying geospatial tools is insufficient, as the technology itself does not explain the changes. Inquiry-based learning and interdisciplinary teaching are pedagogically powerful strategies to complement teaching about environmental change in classroom. Previous research shows that the degree of teacher guidance during the inquiry process influences learning effectiveness when studying changes [26]. The inquiry-driven approach engages students to consider the human dimension of environmental change and gain deeper insights into its social and environmental impacts [32]. Educators need to have students raise questions about hidden driving stakes and forces of changes, such as "what is happening here?", "why does it look like this?", "who was responsible for this?", and "what will happen in the next few years here?".

Predicting long-term outcomes of changes takes the thinking process into imagination and envisioning across different scenarios [33]. The strategy of scenario envisioning can enhance students' awareness of multiple possibilities for the future and stimulate generation of new approaches to unsolved environmental issues [12]. Geography teachers can engage students in visionary exploration of possible different scenarios using big data platforms to strengthen their predicting ability. For instance, under a teacher's guidance, students can observe accurate sea levels under different carbon emission and warming scenarios on the Surging Seas website, resulting in a better awareness of risks of sea level rise and coastal flooding.

## 3. Applying the Framework in School-Based Practice

In this section, we summarize the innovations of the proposed framework and then apply it to guide the lesson design and implementation of classroom activities. An example of various pedagogical ideas is provided, whereby students engage with the topic of deforestation in Southeast Asia using Google Earth.

### *3.1. Innovations of the Framework*

This has been the first attempt to build an educational framework of teaching environmental change toward the uncertain future due to our limited knowledge. It broadens the scope of education for sustainability connecting the past, present and future. Our framework has three major innovations. First, most of the frameworks in previous research aim at learning outcomes regarding content knowledge of environmental issues [34,35], and values and attitudes about sustainability [36]. Instead, our framework highlights the future perspectives and targets environmental thinking, a little researched learning outcome in existing frameworks. Adolescents who process high levels of this type of thinking could look at the future more critically and creatively and take proactive actions to change.

Second, there have been other frameworks that address physical learning environments for environmental education, for instance, engagement with green school buildings in architectural interventions [37]. However, the value of the virtual learning environment is often underrepresented and the role of new technologies in environmental education is not fully appreciated. The major difference of our framework from others is the emphasis on a geographic approach to sustainability education, in which its explicit spatiality is enriched through the use of geospatial technology. This can inform policy makers and educators in providing technology-rich innovative learning environments

that enhance secondary school students' comprehension of the complexity and dynamic nature of sustainability.

Third, given that the concept of environmental change is interdisciplinary [32], this framework is not confined to the discipline of geography but integrates across multiple disciplines towards the goal of nurturing a more holistic understanding. In particular, we articulate in what ways each discipline contributes to teaching environmental thinking skills, designing learning environments and choosing strategies for effective learning of environmental change. How interdisciplinary learning supports teaching the concept of change is illustrated in Figure 2. To be specific, systematic environmental thinking is comprised of diverse cognitive processes, and framing such type of thinking in school subjects needs expertise in cognitive psychology. Mastery of systematic environmental thinking skills is not separated from the subject matter of physical and social sciences, which offer rich contexts for application and transfer of these thinking skills. For instance, knowledge about environmental sciences can be used to explain certain types of change and examine their impacts on ecosystems and built environment. Social anthropology studies the ways in which people live in different social and cultural settings across the globe [15], contributing to deeper understanding of the characteristics of human activities and better interpretation of human-environmental interactions.

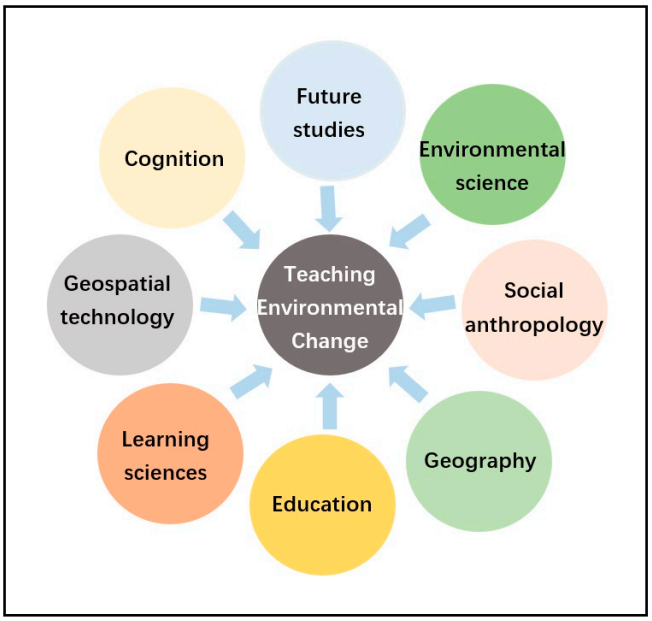



**Figure 2.** A multidisciplinary approach to teach environmental change.

In addition, due to the transdisciplinary nature of spatial patterns and relationships, the use of spatially referenced information and the representation of this information enabled by geospatial technology are important forces for the integration and analysis of information about environmental change [38]. Furthermore, teachers having expertise in the field of learning sciences and education are able to design learning activities integrated with new technology as a way of promoting development of system environmental thinking, and to select proper pedagogical strategies to implement these activities.

### *3.2. An Example: Deforestation in Southeast Asia*

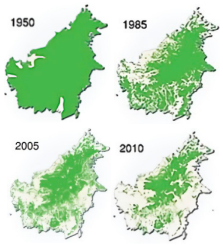
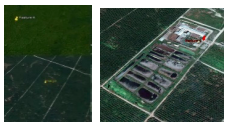
Implementation of our framework in schools can motivate adolescents to take proactive actions for sustainable development, particularly those in developing countries frequently affected by catastrophic natural disasters, island countries vulnerable to sea level rise and areas prone to wildfires. Large-scale deforestation for economic benefits in Southeast Asia has caused environmental problems in this region [39] and this emphasizes the importance of incorporating such issues into the school curriculum and classroom activities. Here we present a lesson plan for teaching human modification of the

physical environment in the topic of deforestation, which aims to increase local students' awareness of environmental crisis.

### 3.2.1. Curriculum

This lesson plan is created to align the key concepts related to 'change' in the geography curriculum document with associated learning outcomes (Table 3). It prompts students' awareness of the dramatic loss of tropical rainforest cover in Indonesia over the past decades and requires them to reflect on possible causes and environmental consequences of such a loss.

**Table 3.** Applying the concept of 'change' in the design of lesson plan.

| Core Theme | | Learning Task | Geospatial Technology |
|---|---|---|---|
| Processes of changes | Describe how sequences of human activities in the physical environment are part of our dynamic planet and changing world. | Identify changes in forest cover in Borneo, Indonesia from 1950 to 2010. |  <br>Map of Borneo<br>  <br>Forest cover (1950–2010) |
| Interdependence | Explain the inter-relationships and interconnections when studying change in physical features. | Explain why there has been such a huge loss of forest cover. |  <br>Forests were replaced by oil palm plantation. |
| Consequences for people and environment | Analyze the positive and negative consequences of humans changing the physical environment. | Predict the environmental effects of the large-scale deforestation in west Kalimantan. |  <br>Forest fire in Southeast Asia<br>  <br>Haze in Southeast Asia |

### 3.2.2. Cognition

The design starts from the key concept of change and arranges knowledge and skills in an increasing complexity. The lesson plan was applied in a Singaporean secondary school geography classroom over two sessions that introduced learners to the topic of deforestation. The students in question were at Secondary 3 (the U.S. Grade 9 equivalent) and were classified as of high learning capability in both content knowledge and technological skills.

#### 3.2.3. Pedagogy

Google Earth, as a freely-available and easy to use example of geospatial technology, supports the effective visualization of geographic processes and events. Rich sources of spatial information, such as maps and photographs that show geographic features evolving over time can be incorporated into Google Earth and displayed as multiple layers [16]. The lesson plan proposed here takes advantage of key features of Google Earth to provide an interactive learning environment for students and enabling them to visualize and analyze human-induced changes (Table 3). The three tasks in the lesson plan can also be taken as assessment questions to evaluate students' learning effectiveness.

With an inquiry-driven approach, the students were guided through instructions of a worksheet to locate Borneo Island in Google Earth. They then opened four layers illustrating spatial distribution of forest cover on this island for different years (1950–2010), whereupon they engaged with interdisciplinary learning. By comparing the layers, the students discovered changes in forest cover on the island and identified west Kalimantan as the region where forest decline has been most prominent. Next, following instructor questions around cause and effect, the students were required to zoom into this region and asked to try and explain the underlying cause(s) of the devasting forest loss. Students then found, to their surprise, that the forests in west Kalimantan have been rapidly replaced by oil palm plantations. To understand the negative consequences of widespread human activities in Borneo, the students were then required to access a further layer indicating the distribution of human-induced forest fires. One student commented, "By putting different layers together, Google Earth allowed us to discover how oil palm plantation is spatially correlated with forest fires". In addition, students were required, under the teacher guidance, to estimate the area in Southeast Asia subject to smoke haze produced when forests were burnt and replaced by oil palm plantations.

In summary, this example demonstrates how different pedagogical approaches work together to assist secondary school students in an investigation of environmental changes brought about by deforestation in Borneo Island. The learning outcomes were structured to align with three themes of "change" in the school curriculum. Geo-visualizations linked to Google Earth tool, including satellite imagery, photographs, maps and data files, proved to be attractive and interesting to the students, and helped them form a more holistic picture of deforestation taking place in this region. Pedagogical strategies aid in the transmission of information and active construction of personal knowledge as to the causes and impacts of deforestation in Southeast Asia, so that students could think beyond the border of academic geography to seek real-life solutions to this urgent issue; this is indeed powerful knowledge. In our lesson plan, acquisition of learning skills related to "change" and powerful knowledge for sustainability proves mutually supportive for future-oriented education. Further lesson plans could then be developed to engage students in discussing viewpoints of different stakeholders, for example, indigenous people, the government, and commercial logging companies, thus elucidating more fully the debate about deforestation.

## 4. Conclusions

The world of the future is complex and indefinite, and preparing future-ready citizens to adapt to these challenges is essential. Given to the state of knowledge regarding human activities and their impact on the environment, this study identifies ways in which the concept of environmental change can be introduced to adolescents in relation to the school curriculum, the students' own spatial and temporal cognition, and pedagogy. In making education a more central and visible part of the response to human-induced environmental changes, we propose a conceptual framework to educate adolescents about their uncertain future. In so doing, we highlight the approaches that for teaching and learning about geography can be adapted for a potentially more effective future-oriented education.

In short, there are valuable suggestions here for future research and best practice in educating about environmental changes. We argue that teaching and learning about the dynamically changing interrelationships between humans and environments can be better achieved by incorporating a wider range of perspectives in social anthropology into the framework, such as culture, politics, economics and history, among others. Moreover, further research on cognitive processes of learning environmental changes is still needed for geography educators to resolve misconceptions and learning difficulties of their students.

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**Declaration of Ethics:** The lesson plan used for this study was implemented in accordance with the guidelines published by American Psychology Association's following the general Ethical Principles of Psychologists and Code of Conduct principles (2002). In addition, the approval from Data Administration Center, Ministry of Education, Singapore was obtained before this study was carried out (ethical approval code: RQ27-12(02)). With this, the students were informed that the participation was fully voluntary and they could retreat at any time. Individual responses to data collection instruments were confidential.

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