Including the Ocean in Formal K–12 Climate Education: Assessment of a Lesson for Middle and High School Students

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Abstract
Formal climate education without consideration of the ocean is incomplete. The effectiveness of a new climate lesson for youth that includes the ocean–climate nexus was examined by delivering the lesson to nine classes situated in separate British Columbia, Canada public schools and assessing the students' understanding of basic climate concepts before and after the lesson. Among the youth assessed, before-lesson *understanding of basic climate science concepts was low. The lesson led to significant improvements in the understanding of climate science; the* after-lesson *level of understanding appears to be a function of age. The classes with the lowest (29%) and highest (73–79%)* after-lesson *class averages were the classes composed of the youngest and oldest students, respectively. The age-related differences are considered with respect to the students' cognitive developmental stage, and suggestions are made to improve understanding among younger students.*

Résumé
Les cours portant sur le climat qui sont donnés dans le cadre du programme scolaire sont incomplets s'ils n'intègrent pas les enjeux océaniques. Le présent article examine donc l'efficacité de la nouvelle éducation au climat qui tient compte de la dynamique climat-océan. Le nouveau modèle éducatif a été présenté dans neuf classes de différentes écoles publiques de la Colombie-Britannique (Canada). Avant et après la leçon sur le climat, la compréhension qu'avaient les élèves des concepts climatiques de base a été mesurée. Avant la leçon, *le niveau de compréhension des élèves était faible, mais s'améliorait beaucoup* après la leçon*, en fonction de l'âge des élèves. Les moyennes les plus faibles (29 %) étaient chez les plus jeunes, les élèves plus vieux ayant obtenu les résultats les plus élevés (73-79 %). Les écarts dûs à l'âge sont analysés en tenant compte du stade de développement cognitif des enfants et des suggestions sont faites pour améliorer la compréhension des plus jeunes élèves.*

Keywords: climate change education, assessment, cognitive development stage, authentic data, hands-on activities, storytelling

Mots-clés : éducation relative aux changements climatiques, évaluation, stade de développement cognitif, données authentiques, activités pratiques, apprentissage par le récit

Introduction

A special report by the Intergovernmental Panel on Climate Change (IPCC), the United Nations body for assessing the science related to climate change, asserts that global warming of 2°C above pre-industrial temperatures will lead to greater impacts than if global warming is restricted to 1.5°C above pre-industrial temperatures (IPCC, 2018). To restrict warming to a maximum of 1.5°C above pre-industrial temperatures will require global net anthropogenic CO_2 emissions to decline by about 45% from 2010 levels by 2030, reaching net zero around 2050 (IPCC, 2018). To achieve these emission reductions will require "rapid and far-reaching transitions in energy, land, urban and infrastructure (including transport and buildings), and industrial systems" (IPCC, 2018, p.15). The IPCC fifth assessment report also indicates that adequate mitigation, that is, actions intended to reduce anthropogenic emissions of greenhouse gases (GHGs), poses "substantial technological, economic, social and institutional challenges, which increase with delays in additional mitigation" (IPCC, 2014, p. 20). Furthermore, the IPCC (2014) states that "delaying additional mitigation increases mitigation costs in the medium to long term" (p. 24). Moreover, if there are considerable delays in additional mitigation, then constraining warming to 2°C over pre-industrial temperatures will not be possible over the 21st century (IPCC, 2014). Ambitious mitigation plans not only require citizen endorsement so that governments have the political space to make the required changes (Lee et al., 2015; Watkins, 2007), but also require citizens in industrialized nations to actively reduce their personal GHG emissions (Anderson, 2010). Indeed, as indicated in Canada's mid-century long-term low-greenhouse gas development strategy (Environment and Climate Change Canada, 2016), reducing GHG emissions will require "substantial effort on the part of all Canadians" (p. 3).

Improving knowledge of climate change through formal education is an important step toward acquiring citizen endorsement of government mitigation programs and reducing individual GHG emissions (Anderson, 2010; Brownlee et al., 2013; Busch et al., 2019; Lee et al., 2015; Shi et al., 2016; Trott, 2019). There is ample evidence that students, teachers, and the public do not have adequate knowledge of the basic science of climate change (Bofferding & Kloser, 2015; Duffy et al., 2019; Hestness et al., 2014). If citizens are to reduce their personal GHG emissions, they need to understand foundational concepts of climate change and its complex causality chains (Lehnert et al., 2019) to make effective choices that impact the climate system (Bofferding & Kloser, 2015; Karpudewan et al., 2015). Indeed, due to the complex interplay between factors such as ideology, social norms, efficacy, hope, concern, and certainty, knowledge alone may not be sufficient to significantly improve personal mitigation (Busch et al., 2019; Hoffman, 2011; Tolppanen et al., 2020). It can, however, enable informed decisions (Anderson, 2010; Bofferding & Kloser, 2015; Busch et al., 2019; Tolppanen et al., 2020).

Formal climate change education is also important as it can offset the negative influence of ideology and worldview on climate change opinion (Busch et al., 2019; Guy et al., 2014). Without formal climate change education, misinformation and misconceptions can fill the void, leaving citizens misinformed and prone to biased assimilation or confirmation bias (Brownlee et al., 2013; Fortner, 2001; Hestness et al., 2014; McBean & Hengeveld, 2000). Finally, there is a moral imperative to educate youth on climate change. This education may facilitate societal transformation as youth can be effective knowledge bearers and powerful agents of change (Anderson, 2010; Bond et al., 2021; Lawson et al., 2018; Trott, 2019; Trott & Weinberg, 2020).

Formal Climate Change Education in Canada

Formal climate change education within K–12 curricula exists in Canada, but it does not consistently reflect either current scientific understanding or jurisdictional (province and territory) climate policies. While all jurisdictional climate policies focus on the need for education to contribute to addressing climate change, there is a comparative lack of attention given to climate change in education policy across jurisdictions (Bieler et al., 2018). This deficiency in formal climate change education may be attributed to a lack of coordination between climate and education policymakers (Bieler et al., 2018). Another possible reason for this shortcoming may be that jurisdictional K–12 curricula are guided by the Pan Canadian Science Curriculum (PCSC), in which inclusion of climate change education is very limited (Council of Ministers of Education Canada [CMEC], 1997). In 2009, UNESCO issued a supplementary policy statement stressing climate change education must be included in all education systems "if the necessary changes in society are to be effected in time" and subsuming climate change education under education for sustainable development (Nazir et al., 2011, p. 365). In Canada, climate change education occurs within environment and sustainable development courses (Bieler et al., 2018)—courses that are typically electives. There is variability in mandatory climate change education across jurisdictions (Bieler et al., 2018; Wynes & Nicholas, 2019), and erroneous information exists in some curriculum documents and textbooks (Wynes & Nicholas, 2019).

A recent national survey was conducted to understand levels of knowledge and perceptions of climate change among public, parents, youth, and educators in Canada (Field et al., 2019). The survey found that formal educators are the primary source of climate change education for youth; among those teaching climate change education, each dedicates only 1–10 hours to climate change education per year. A significant portion of the educators do not have a solid understanding of climate change and acknowledge they do not feel prepared to teach the subject. Thus, it is not surprising that 43% of Canadians (general public) surveyed failed a climate change knowledge test. Nevertheless, most

Canadians (general public) are concerned about climate change, support more climate change education for Canadian youth, and believe that climate change education should be an educational priority.

Inclusion of the Ocean–Climate Nexus

Within the PCSC there is no mention of the ocean–climate nexus; yet, without consideration of the ocean, climate change education is incomplete. By absorbing a significant portion of carbon dioxide emissions (39%, depending on atmospheric carbon dioxide concentrations) (McKinley et al., 2020) and 90% of heat generated from GHG emissions (IPCC, 2007), the ocean buffers the Earth from extreme heating. The ocean also provides a host of ecosystem services (e.g., water, oxygen, food, medicines, minerals) that support the health and socio-economic well-being of society (Lemmen et al., 2016; Glithero, 2020) and are a critical source of food, culture, and spiritual support to Inuit and First Nations (Lemmen et al., 2016). If it were a country, the annual gross marine product places the ocean as the world's seventh largest economy, with at least two-thirds relying on a healthy ocean (Hoegh-Guldberg, 2015). Despite its vastness, the ocean is being degraded by multiple stressors, and human-caused climate change is a dominant stressor (United Nations [UN], 2017). Climate change is impacting the ability of the ocean to provide the services/conditions that humans and other life require (UN, 2017).

Opportunities, however, do exist for the ocean to contribute to achieving temperature stabilization goals (Hoegh-Gulderg et al., 2019), which also represent future career opportunities for Canadian youth. In Canada, British Columbia (B.C.) is considered a leader in climate policy (Bieler et al., 2018) and is also significantly dependent on its adjacent marine environment. Yet, within the B.C. K–12 curriculum, the ocean environment is only a significant component of climate change education for Earth Science 11, Environmental Science 12, and Physical Geography 12, and is not included in the mandatory courses containing climate change education (Science 7 and 9, Social Studies 10). Not surprisingly, a recent survey found that only ~10% of Canadians surveyed consider ocean warming and climate change to be a significant threat to the ocean (Glithero, 2020). The ocean–climate nexus is a fundamental component of climate change science, and its inclusion in formal climate change education would contribute to Canada's ocean literacy (an understanding of ocean's influence on us, and our influence on the ocean) initiatives within the United Nations (UN) Decade of Ocean Science for Sustainable Development (2021–2030). Indeed, many aspects of Canadian ocean literacy (e.g., importance of science, economics, communication, informed decisions, behavioural change, interdisciplinary learning, inclusion of Indigenous perspectives and knowledge, social justice) (Stewart, 2019) overlap with climate literacy.

Teaching climate change can be challenging for teachers. There can be a reluctance to teach that which is deemed controversial among peers/parents/

administrators (Field et al., 2019; Hestness et al., 2014; Monroe et al., 2019). Teachers also feel they lack the time and skills to adequately deliver climate change education instruction, address controversies (Hestness et al., 2014; Lehnert et al., 2019; Monroe et al., 2019; Tolppanen et al., 2020), and regulate and/or respond to student emotions resulting from climate change education (Ojala, 2016). Most Canadian teachers indicate that they require resources (e.g., lesson plans) and more professional development to teach climate change education (Field et al., 2019). Including the ocean–climate nexus within formal climate change education can be challenging for many teachers because, unfortunately, many Canadian teachers do not have the capacity (e.g., time, resources, educational background) to incorporate ocean education into their mandated curriculum (McPherson et al., 2020).

An Ocean–Climate Science Lesson

Given the role that education can play in improving climate change mitigation, the importance of educating youth specifically, the lack of understanding among Canadians regarding the ocean–climate nexus, and the need among teachers for a climate change education resource that includes the ocean, the Learning & Community Engagement department at Ocean Networks Canada (of whom the authors are a part)[1] created a climate science lesson for middle school (MS, Grades 6–8) and high school (HS, Grades 9–12) students (www.oceannetworks.ca). This lesson is freely available (contact: learning@oceannetworks.ca) and examines causes of climate change and impacts of climate change on the ocean with hands-on activities, authentic data from Ocean Networks Canada (ONC) observatories, and Inuit Traditional Ecological Knowledge (TEK). As well, the lesson encourages students to think of and act on solutions to climate change. We used hands-on activities to mean, “students are actively engaged in manipulating materials,” to facilitate the development of knowledge, skills, and attitudes - major dimensions of learning in science (Flick, 1993, p. 2), and an interest in the subject (Holstermann et al. 2010). We used data in various forms (video, camera, acoustic, and scalar) to engage students, teach ocean concepts, and to facilitate the development of analytical and problem-solving skills (Greengrove et al., 2020). By Inuit TEK, we refer to knowledge of climate change that Inuit have established over millennia through their ongoing observations and close relationship with the natural environment for survival, sustenance, travel, and cultural practice.

The lesson addresses the need for improved education on climate science, a target objective of the United Nation Sustainable Development Goal (SDG) 13 “Climate Action,” which includes the following specific objectives: improve education, awareness raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning (UN, 2015). The lesson also addresses SDG 14 “Life Below Water,” which outlines the following specific objectives: the learner knows the basic premise of climate change and the role of the oceans in moderating our climate; the impact humanity is having on the oceans (UN, 2015). Our objective was to create a lesson that improves understanding of basic climate and ocean–climate facts. We repeated the lesson with nine classes (four middle school and five high school) situated in separate B.C. public schools and, with a simple written quiz, we evaluated student understanding immediately before and after the lesson.

Instructional Method

While there are many effective instructional models, for our lesson we chose the 7E instructional model, an adaptation of the 5E instructional model wherein students build understanding through a 5-stage learning sequence (Engage, Explore, Explain, Elaborate, and Evaluate). Developed in the 1980s, the 5E instructional model is grounded in constructivist theory and is widely used because of its effectiveness in improving student understanding (Bybee et al., 2006; Karpudewan et al., 2015). The B.C. curriculum requires that teachers incorporate Indigenous perspectives and knowledge where possible, and this knowledge creates a more holistic understanding of complex concepts. The First Nations Education Steering Committee, a policy and advocacy organization representing First Nations in B.C., proposed the 7E instructional model wherein *Elder* and *Environment* are added to the 5E model so as to facilitate the incorporation of Indigenous knowledge (Bernabei et al., 2019). The following subsections outline our specific pedagogical approach within the 7E instructional model (Engage, Explore, Explain, Elaborate, Elder and Environment, Evaluate), and includes an additional section entitled "Lesson Conclusion."

Engage

Stories and entertainment are effective means through which to engage learners and build their trust (Brownlee et al., 2013; Flora, et al., 2014). Thus, as part of our introduction to Ocean Networks Canada, we used the freely available data from Oceans 2.0 (ONC's data management system at https://data.oceannetworks.ca) in an entertaining personal story format to pique student interest in the ocean and convey the message that scientific data are integral to making informed decisions with respect to ocean management, disaster mitigation, and environmental protection. For example, in one instance, we shared a humorous personal story of a hagfish and then played an excerpt of a video (https://youtu.be/nzMB8jqioV0?t=78), which we muted, to engage the students in the initial stages of the scientific process: What do you think is going on here? Who are these animals? What happened and how could that have happened? What depth is this, and what might be the scientific implications of this discovery? We also played the full video (https://youtu.be/nzMB8jqioV0) to emphasize that scientists don't know everything and new discoveries are continually being made not only by scientists but also by citizens and students.

Explore

Effective educational strategies allow for an exploration of how the lesson topic is of personal relevance to students (Hestness et al., 2014; Monroe et al., 2019). Thus, as an introduction to the *Explore* phase, students had the opportunity to discuss their understanding of climate change and its relevance to them. This was done as a class, but it could also be done in smaller student groups. This was followed by a short (~10 minute) teacher-led presentation on climate change and warming in the ocean. The students were prompted with the question, "How does warming impact the ocean?" Educational programs that have engaging hands-on activities, are learner-centred (i.e., learners create their own understanding), collaborative, and follow the scientific process lead to improved learning (Holstermann et al., 2010; Lehnert et al., 2019; Monroe et al., 2019). Thus, to explore answers to the driving question, "How does warming impact the ocean?", students gathered into small groups and visited three activity stations, rotating between stations every 15–20 minutes. At each station, students were provided with a background summary on a scientific concept (gas solubility, ocean acidification, and Arctic sea ice). They worked together to formulate a hypothesis that the activity addressed and conduct the activity by following procedures. At the conclusion of the activity, students were asked if the results supported their hypothesis. If the results did not, then they had an opportunity to revise their hypothesis. They then tested their hypotheses, with authentic ocean data, in the Elaborate phase of the lesson. Given time constraints, at each station there was one teacher or facilitator available to help students. For logistical reasons, the ocean acidification activity was done at the same time as the activities related to impacts from warming. This was explained at the start of the hands-on activities.

Explain

Allowing students the time to explain their learning can give them a better understanding of climate science, particularly if there are deliberate discussions that challenge them to explain their understanding (Monroe et al., 2019). Thus, the class convened after the station-based activities, at which time the teacher prompted students to explain their observations. Below is an example of a discussion regarding the gas solubility activity,

> Teacher: What happened to gas solubility when the water temperature increased?
> Students: Silence.
> Teacher: What was within the bubbles?
> Students: Carbon dioxide.

Teacher: What happened to the bubbles in the pop as temperature increased?
Students: Bubbling increased (at first).
Teacher: Where did those bubbles of carbon dioxide go?
Students: Burst at surface.
Teacher: Where did the carbon dioxide go then?
Students: Air.
Teacher: So, does warm water hold more or less carbon dioxide?
Students: Less.

Following this discussion portion of the lesson, students learned that although this activity focused on carbon dioxide gas, other gases (e.g., oxygen) behave similarly. In other words, as water temperature increases, it holds less oxygen gas. This type of discussion occurred for each of the activities. After this discussion, the students received a short (~15 minute) teacher-led presentation that gave teachers the opportunity to augment student explanations. Where appropriate, figures of authentic data were included in the presentation (e.g., sea ice data from the Arctic, atmospheric carbon dioxide concentrations, pH of seawater with respect to time). We used authentic data for several reasons. First, students gain experience (with some scaffolding) in describing, analyzing, and interpreting data—important skills for facilitating their independent interpretation of data (Greengrove et al., 2020). Second, interpreting data improves understanding of concepts (Greengrove et al., 2020; Monroe et al., 2019), which helps students to communicate more confidently and competently on the topic of climate science (Gold et al., 2015; Sloane & Wiles, 2020) and counter skeptical claims (Monroe et al., 2019). Third, research indicates that an understanding of the root causes of climate change leads to better choices regarding mitigation (Bowers et al., 2016). Finally, an examination of data over long time periods allows for the patterns of climate change to be more easily ascertained. This overcomes the problem of humans having difficulty noticing the impacts of climate change over their personal lifetime (Brownlee et al., 2013; Fortner, 2001).

Elaborate

To improve and extend student understanding of climate concepts and test their hypotheses developed during the *Explore* phase, students were presented with ocean data from different Ocean Networks Canada coastal observatories. For example, to test their hypothesis developed at the gas solubility station (e.g., *As temperature increases/or decreases, the solubility and availability of oxygen declines/or increases*), the students were presented with data on ocean temperature and oxygen concentration from a coastal B.C. observatory. Likewise, to test their hypothesis developed at the Arctic sea ice station (e.g., *Increases in global temperatures have dramatic effects on sea ice and the ecosystem and communities that depend upon the sea ice)*, the students were presented with data on sea ice dynamics and temperature from a coastal Arctic station in Cambridge Bay, Nunavut, Canada. With enough time and teacher scaffolding, the students determined how to test their hypotheses with the data. For example, students plotted oxygen concentration with respect to temperature and found that it supported the hypothesis that as temperature increases, the availability of oxygen declines. However, analysis of the eight-year data set on sea ice dynamics and temperature from Cambridge Bay did not support their hypothesis regarding the impact of temperature on sea ice. This data set, given its relatively short duration, showed more influence of inter-annual variability than a discernible long-term trend. This provided an ideal opportunity to discuss the value of long-term data sets and explain that Inuit TEK represents a unique long-term data set of Inuit observations of sea ice.

Elder and Environment

Inuit are strongly connected to their local environment and have maintained a collective memory of nature via their shared oral histories and cultural stories that have passed through generations since time immemorial (Brownlee et al., 2013). Inuit knowledge of climate change represents the longest human record of observations in the Canadian Arctic and is an invaluable source of information on change, adaptation, mitigation, and survival (Gérin-Lajoie et al., 2016). With respect to sea ice, this detailed knowledge is essential to supporting today's transportation, hunting, recreation and cultural activities, in addition to informing long-term understanding of how climate change is affecting the Arctic Ocean environment. During a project to understand changing sea-ice in the region (Polar Knowledge Canada funded study, M. Hoeberechts et al.) Inuit knowledge holders from three communities (Kugluktuk, Cambridge Bay, and Gjoa Haven) in the Kitikmeot Region, Nunavut shared their observations of changes in the sea ice and how these changes are impacting their way of life. These observations were presented to the students. Through this aspect of the lesson, students were introduced to the idea that scientific data can be complemented by other sources of knowledge, which adds richness to the understanding of complex phenomena and addresses a key curricular competency in the B.C. Curriculum (to apply First Peoples perspectives and knowledge as other ways of knowing and sources of information). This TEK helped students evaluate hypotheses they formulated during the Arctic sea ice hands-on activity. For southern students, who may not yet perceive the extent of climate change impacts on their daily lives, the observations shared by Nunavummiut can appeal to their altruistic value systems as they are exposed to people and communities currently experiencing disproportionate impacts of climate change. Sharing these realities can have the further effect of facilitating pro-environmental behaviour, such as mitigation (Busch et al., 2019; Monroe et al., 2019).

Lesson Conclusion

Education on climate change is intended to improve knowledge of climate change and motivate students to reduce their GHG emissions. It is not intended to leave students in a state of despair (Duffy et al., 2019; Kelsey & Armstrong, 2012). With this in mind, the final phase of the lesson was devoted to a student-led discussion with the aim of empowering them to build on their knowledge and propose effective and immediate personal actions to reduce GHG emissions in their local community.

Because we were visitors in their classroom, we did not have the time to fully develop this discussion with the students. However, we encouraged the teacher and students to continue the discussion as this phase of the lesson has several theoretical benefits. First, it allows students to express their emotions regarding climate change and action; such expression is an important first step toward addressing environmental problems (Barrows, 1998). Having students express their emotions within the classroom is also beneficial as educators can respect and/or validate their emotions which, in turn, improves overall learning and action (Ojala, 2016). For example, a common frustration students express is that their individual actions are insignificant compared to the magnitude of the problem (Kenis & Mathijs, 2012). As educators, we can validate this frustration; however, we can also model how we cope with this frustration. In the case of the lesson outlined above, we discussed the responsibilities of citizenship in a global society (Westheimer, 2015) as well as "bright spots" (Duffy et al., 2019) in human history where collective action solved or alleviated problems.

Second, giving students autonomy to critique their local community and envision a better future can convey the message that their ideas are valuable (Haynes & Tanner, 2015; Kenis & Mathijs, 2012; Woolfolk et al., 2009). This can boost their self-determination and motivation, and it can empower them to create change/be the change they want to see (Kelsey & Armstrong, 2012; Kenis & Mathijs, 2012; Ojala, 2016; Trott, 2019; Woolfolk et al., 2009). It can also shed light on the complexities of climate mitigation (e.g., ethical, economic, sociological, political) and the need for focusing our efforts here rather than debunking accepted climate science (Busch et al., 2019). Finally, it allows for an informal assessment of their understanding of the foundational concepts of climate change: If their understanding were complete, then they would make effective choices that impact the climate system (Bofferding & Kloser, 2015; Karpudewan et al., 2015) and be considered climate literate (Duffy et al., 2019).

Evaluation

The primary goal of the lesson was to improve understanding of some key climate and ocean–climate facts. Prior to the lesson, we gave the students a quiz, which we then repeated with them after the lesson. We used a quiz as this is a format with which students are familiar. Students provided their written answers to seven questions on basic climate and ocean–climate science (Table 1). The quiz, as given to students, is provided in Appendix A. Written answers were graded (i.e., assigned a mark) using the answer key (Table 1). The *before-lesson* and *after-lesson* grades for each class were the basis of our analysis of the lesson's effectiveness (i.e., its ability to improve understanding of basic climate and ocean–climate facts). An example of the data (grades) from one classroom is provided in the Appendix B. With the exception of two instances, all students provided written answers to the questions. In one instance, the teacher forgot to provide the students with a question. In the other instance, there was an undetected typographical error in one question which made the question difficult to interpret; for this instance, answers were not included in our analysis. For each class, paired t-tests and a significance level of 5% were used to determine if before and after grades were significantly different (Zar, 1984). An example of the results of a paired t-test for one classroom is provided in Appendix C.

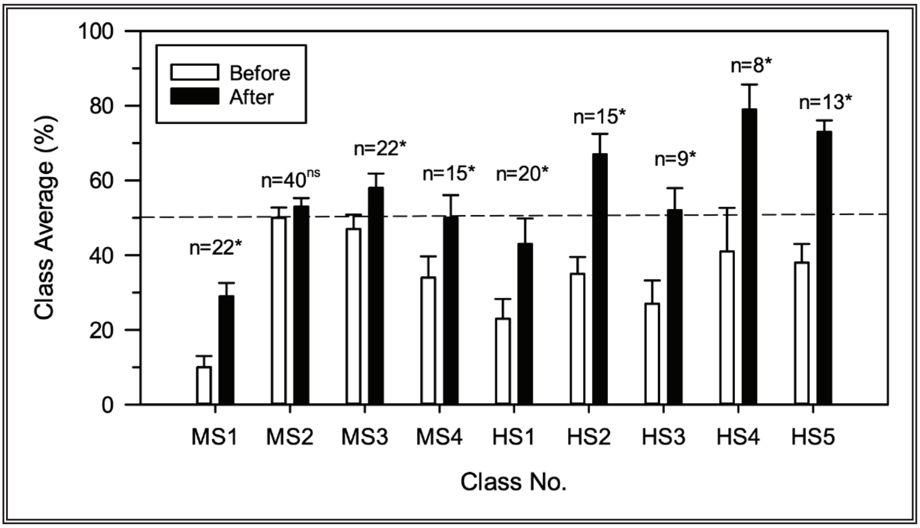
Question	Answer Key *(total possible mark)*
1. What is the definition of a greenhouse gas?	A gas that absorbs and emits infrared radiation (1)
2. The most important man-made greenhouse gas is considered to be:	Carbon dioxide (1)
3. What two human activities lead to carbon dioxide increasing in the atmosphere?	Deforestation and burning fossil fuels (2)
4. In Canada, what are the main sources of carbon dioxide emissions?	Transportation and stationary combustion (manufacturing, residential, commercial/ institutional,oil and gas production, refineries) (2)
5. List two impacts of warming on the ocean	Reduced oxygen, sea ice melting (other answers are possible e.g. habitat range changes, coral reef die-offs, food web changes, sea-level rise) (2)
6. What causes ocean acidification?	Carbon dioxide gas reacting with seawater (1)
7. What does ocean acidification do to marine biota with calcium carbonate shells?	Makes it harder for them to make their shells; dissolves their shells (1)

Note. These questions were provided before and after the lesson. Students accessed the information for questions 1-4 and 5-7 through the presentation and hands-on activities, respectively.

Table 1 *Quiz Questions (And Answer Key) Used to Evaluation Understanding of Some Basic Climate and Ocean-Climate Science Facts.*

Results and Discussion

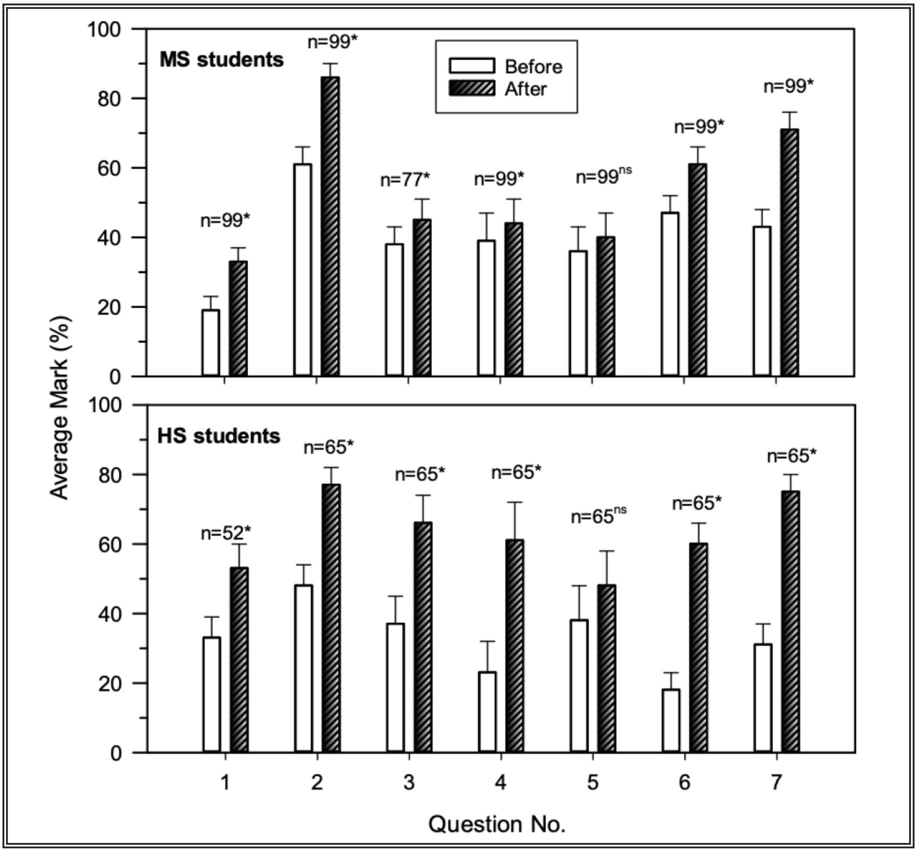
Middle school (MS) and High school (HS) students' before-lesson understanding of basic concepts and information regarding climate science was low (Fig. 1). If 50% is considered a passing grade, then the before-lesson class averages indicate that all classes but one had a failing grade. Questions 1 to 4 were selected as basic climate change science knowledge that would be expected in any course covering climate science in Canada. Questions 5 to 7 pertain specifically to the ocean and are not found in mandatory courses of the B.C. curriculum; therefore, the content is less likely to have been taught by teachers prior to our lesson. However, *before-lesson* averages for questions 5 to 7 were similar to *before-lesson* averages for questions 1 to 4 (Fig. 2). The low (i.e., <50%) *before-lesson* average grades among the MS (Grades 6–8) students were not surprising. Within the B.C. K–8 curriculum, Science 7 is the only mandatory course that specifically includes climate science. Prior to our lesson, MS1 (composed of Grade 6 and 7 students) had not yet received formal instruction in climate science, and this would explain their low level of *before-lesson* understanding. Typically, students with more science classes have more knowledge of climate science (Busch et al., 2019). The other MS



Note. Dashed line denotes an average grade of 50%. MS1–4 are middle school classes (MS1—Grade 6/7, MS2—Grade7, MS3,4—Grade 8). HS1–5 are high school classes (HS1,2,3—Grade 10, HS4,5—Grade 12). For each class, the sample size (*n* = number of students in class) is denoted and whether *before-lesson* and *after-lesson* marks were significantly different (paired *t*-tests: *ns* and * refer to not significantly and significantly different, respectively).

Figure 1. Class Average Marks (± S.E.) for Each Class Before and After the Climate Lesson

classes (Grades 7 and 8) had received formal climate science education once previously (MS2 just prior to our lesson, and MS3,4 the year before) which may explain their higher *before-lesson* average grades (compared to MS1).It is surprising that the HS students had low *before-lesson* average grades as they certainly had received more science education than the MS students. Identifying reasons for low *before-lesson* understanding among HS students was beyond the scope of this study but does warrant further investigation as it suggests that HS students may graduate with an inadequate understanding of basic concepts regarding climate change science. Certainly, recent data showing that a large portion of the general Canadian public do not understand climate change support this conclusion (Field et al., 2019).



Note. For each question, the sample size (*n* = total number of students) is denoted and whether *before-lesson* and *after-lesson* marks were significantly different (paired *t*-tests: *ns* and * refer to not significantly and significantly different, respectively).

Figure 2. Average Marks (± S.E.) for Each Question, Before and After the Climate Lesson, for Middle School (MS) and High School (HS) Students

With the exception of one class, the climate lesson led to significant improvements in the understanding of climate change science (Fig. 1). Among the students assessed, the level of understanding after the lesson was age-related (Fig. 3). The classes with the lowest (29%) and highest (73–79%) after-lesson class averages were the classes composed of the youngest (MS1—Grades 6 and 7) and oldest students (HS4,5—Grade 12), respectively. All the other classes, composed of Grades 7, 8, and 10 students, developed a level of understanding that was between these extremes (Fig. 2, 3).

One possible explanation for the age-related difference in improvement in understanding is that some of the fundamental concepts of climate change are abstract, and the cognitive developmental stage of younger students prevents these students from fully understanding climate concepts (Fortner, 2001; Strickhouser et al., 2017). Examining the data by question indicates that the MS students didn't develop the level of understanding that the HS students developed because they didn't do as well on questions 1, 3, and 4 (Fig. 2). This is likely because the information necessary for accurately answering questions 1, 3, and 4 wasn't made available in a manner fitting for the MS students' cognitive developmental stage. The information for questions 1, 3, and 4 was available from presentations slides (note that although information for question 2 was also available from presentation slides, it is likely that MS students attained a high level of understanding for question 2 because they had a good understanding of the question before the lesson). In contrast to the hands-on activities, where learning occurs through tangible interaction with materials, learning from presentation slides requires more abstract thinking. Research on cognitive development indicates that children (McMahan & Thompson, 2015), beginning at 11–12 years old, are developing an abstract system of logic to understand the world. However, whether they use this system effectively depends on various factors, such as time provided for solving the problem and the content of a problem. Problems that are not personally relevant or do not align with children's own thinking are less likely to be processed correctly. Overall mental ability increases with age; adolescents have a more developed abstract system of logic, faster processing speeds, better working memory and fluid intelligence, and better divided and selective attention.

Following research on cognitive development (McMahan & Thompson, 2015), MS student understanding of questions 1, 3, and 4 would improve if they were given more time to process the information on these slides, if the information on the slides was made more personally relevant, and if time was allotted to discussing information with respect to their prior thinking. Dynamic visualizations might also help to improve understanding of abstract climate science concepts (Hestness et al., 2014). Nevertheless, the results indicate that the lesson led to significant gains in the understanding of climate change science among MS and HS students, and higher *after-lesson* levels of understanding of climate science among HS students.

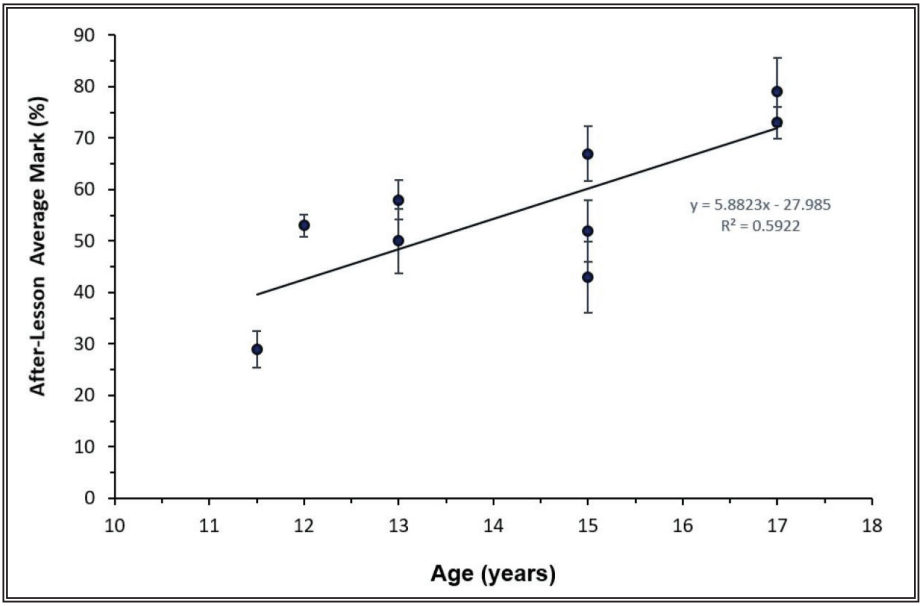


Figure 3. Class Average Marks (± S.E.) After the Climate Lesson

From the outset, we designed the lesson so that teachers could readily use it in their classroom, and so that students could increase their understanding of climate science in order to propose effective and immediate personal actions to reduce GHG emissions in their local community. Based on a variety of anecdotes and feedback, the teachers found the lesson useful. During the final phase of the lesson, we had enough time for a short student-led discussion. In general, the students proposed effective and immediate personal actions to reduce GHG emissions in their local community. For example, solutions by this group of students (https://youtu.be/8d3lnEEBoco) are representative of the solutions proposed by MS and HS students. Given that youth have the capacity to inform decision making, communicate risks, and facilitate action (Haynes & Tanner 2015; Lawson et al., 2018), we encouraged classroom teachers to provide more time and space for students to develop their ideas and create climate action projects in their local community. Locally relevant climate action projects have many advantages. For example, they can create a sense of agency in students, which can in turn sustain students' interest and inspire their active participation (Trott, 2019). They can also lead to higher order thinking (vis-à-vis Bloom's taxonomy), and they can contribute to environmental citizenship and a "We can fix it" focus (Wynes & Nicholas, 2019, p. 14). In the process, students exercise attitudes articulated in the PCSC (e.g., work collaboratively in carrying out investigations as well as in generating and evaluating ideas; be sensitive to and responsible about maintaining a balance between the needs of humans and a sustainable environment; become aware of the consequences of their actions; appreciate the role and contribution of science and technology in our understanding of the world). With respect to the B.C. curriculum, students can exercise competencies such as: a) considering the social, ethical, and environmental implications of the findings from their own and others' investigations; and b) contributing to care for self, others, community, and world through personal or collaborative approaches.

While the lesson examined in this study improved understanding of climate change and the ocean–climate nexus among MS and HS students assessed, it is important to acknowledge the limitations of this study. For example, the sample size was small and non-randomized (i.e., we were contacted by teachers interested in receiving our climate lesson). Thus, the students in this study were not representative of students in B.C. or in Canada. The study also used the same quiz for evaluating improvement in understanding. A potential limitation of this assessment strategy is that it may have led to before-evaluation learning. Moreover, the wording of questions may have posed difficulty for some students. While the study did assess improvement in understanding, there was no evaluation of the longer-term retention of this understanding. A more detailed assessment study would address the limitations of the present study.

Conclusion

As stated by the United Nations, "climate change is the defining issue of our time, and we are at a defining moment" (UN, 2018). At present, Canadians do not have a complete understanding of climate change (Field et al., 2019) and yet this understanding is needed to acquire citizen endorsement of government mitigation programs and to reduce individual GHG emissions. Formal education is key to advancing this understanding. As Canadian provinces and territories revise their K–12 curriculum documents, climate change education (that includes the ocean) must be a priority. Given that curriculum documents are typically revised approximately every 15 years (Wynes & Nicholas, 2019), and that carbon dioxide emissions must be reduced by 45% (of 2010 levels) in the next nine years, curriculum revisions for climate change education must be expedited. Teachers face challenges with regard to teaching climate change science in general and the climate–ocean nexus in particular. They would not only benefit from professional development on climate change education but also from researched, tested, and effective classroom-ready resources on this critical issue. Ideally, this research would bring together educators, research scientists, and education and climate policy makers, and it would incorporate resources and lessons learned from the diversity of non-governmental organizations and informal educators across the country. Such educational resources would vastly improve climate change education teaching capacity across Canada at a critical time and would contribute to Canada's ocean literacy initiatives within the UN Decade of Ocean Science for Sustainable Development.

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Footnotes

1 Ocean Networks Canada is an initiative of the University of Victoria that uses cabled observatories, remote control systems, interactive sensors, and big data management to monitor the geological, physical, chemical, and biological oceanography of the west and east coasts of Canada and the Arctic. The data are used for scientific research to help communities, governments, and industry make informed decisions on ocean management, disaster mitigation, and environmental protection and are also available to anyone interested in the ocean.

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Evaluation

What is your current knowledge of greenhouse gases and impacts of warming and carbon dioxide on the ocean? Please answer the questions below to the best of your ability. Do not use electronic devices or textbooks to find answers. Answer questions on your own.

Student Name: ____________________________

1. What is the definition of a greenhouse gas?

____

2. The most important man-made greenhouse gas is considered to be:

____

3. What two human activities lead to carbon dioxide increasing in the atmosphere?

____

4. In Canada, what are the main sources of carbon dioxide emissions?

____

5. List two impacts of warming on the ocean:

____

6. What causes ocean acidification?

____

7. What does ocean acidification do to marine biota with calcium carbonate shells?

____

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Appendix A. Quiz, to assess basic knowledge, given to students.

St. No.	Q1 (b)	Q1 (a)	Q2 (b)	Q2 (a)	Q3(b)	Q3(a)	Q4(b)	Q4(a)	Q5(b)	Q5(a)	Q6(b)	Q6(a)	Q7(b)	Q7(a)	Total Mark Before	% Grade Before	Class Avg (%) Before (± sd)	Total Mark After	% Grade After	Class Avg (%) After (± sd)
1	0	0	1	1	1	2	0	2	0	1	1	0	0	1	3	30	34	7	70	50
2	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	22	3	30	24
3	0	0	1	1	1	2	0	2	0	0	0	0	0	1	2	20		6	60	
4	1	0	0	1	1	1	0	1	0	0	0	0	1	1	3	30		4	40	
5	1	1	1	1	1	1	1	2	1	1.5	0.5	1	1	1	6.5	65		8.5	85	
6	0	0	1	1	0	1	0	1	0	0	0	1	0	1	1	10		5	50	
7	0	0	0	1	0	0	0	0	2	0	0.5	0	0	0	2.5	25		1	10	
8	0	1	1	1	1	1	0	1	0	1	1	1	1	1	4	40		7	70	
9	0	0	0	1	0	1	0	1	0	0	0	1	0	1	0	0		5	50	
10	0	0	0	1	2	2	1	2	0	0	0	0	1	1	4	40		6	0	
11	1	0	1	1	1	2	2	2	1	1	0	1	1	1	7	70		8	80	
12	0	0	1	1	1	1	2	1	0	1	0	1	1	0	5	50		5	50	
13	0.5	0	1	1	1	1	2	2	1	1	0	0	1	1	6.5	65		6	60	
14	0	0	1	1	1	1	0	2	1	0	0	1	0	1	3	30		6	60	
15	1	0	1	1	1	1	0	0	0	0	0	1	1	1	4	40		4	40	

Appendix B. Example data from classroom MS4. This classroom had a total of 15 students. Each student was assigned a number (St. No.). Students were given the same quiz before and after the lesson. See Table 1 for questions, and total possible marks per question. Grades are listed by question (Q). Grades earned before and after the lesson denoted as "b" and "a", respectively.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
% Grade Before	15	34.33	22.03	5.69
% Grade After	15	50.33	23.79	6.14

St. No.	% Grade Before	% Grade After
1	30	70
2	0	30
3	20	60
4	30	40
5	65	85
6	10	50
7	25	10
8	40	70
9	0	50
10	40	0
11	70	80
12	50	50
13	65	60
14	30	60
15	40	40

Estimation for Paired Difference

Mean	StDev	SE Mean	95% CI for μ_difference
-16.00	24.80	6.40	(-29.73, -2.27)

μ_difference: mean of (C2 - C3)

Test

Null hypothesis	H_0: μ_difference = 0
Alternative hypothesis	H_1: μ_difference ≠ 0

T-Value	P-Value
-2.50	0.026

Appendix C. Example paired *t*-test results for classroom MS4.