An Analysis of Introductory Environmental Science Textbooks' Approaches to Commonly Held Climate Change Misconceptions

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Abstract

A climate literate public is becoming increasingly important as the threats of climate change grow (Johnston 2019). Climate literacy is taught across introductory environmental science courses in higher education institutions in Canada with textbooks being used as a key tool in facilitating climate literacy in these cases (Choi et al. 2010). This study aims to evaluate how these textbooks are approaching their delivery of commonly held climate change misconceptions.

A literature review was conducted to determine prevalent misconceptions and key textbook elements that enhance learning while also combatting misconceptions. The climate change and atmospheric science chapters from eight textbooks used among the top 15 research universities in Canada were analyzed to determine the presence or absence of the six most commonly recorded misconceptions and whether or not the misconceptions were presented using the key five textbook elements. A checklist containing the misconceptions and textbook elements was used to identify and further code textbook elements; each time a check mark was given, the key terms and associated content segments were also recorded.

The results show that some key textbook elements were heavily underrepresented across all misconceptions and textbooks. Misconceptions were only directly refuted by the textbooks in 6.25% of the time. Some misconceptions were frequently presented without the inclusion of select textbook elements. Only one out of eight textbooks used examples when presenting misconceptions around the greenhouse effect. Two out of eight textbooks used prompting questions and none used case studies or examples when presenting concepts related to misconceptions of water vapour's role as a greenhouse gas. The results also showed some similarities in the presentation of concepts across all textbooks. The phrases 'short term' and 'long term' were used across all but one book when presenting the difference between weather and climate.

Refuting misconceptions is one of the most effective strategies that can be used to help learners overcome these misunderstandings (Nussbaum et al. 2018). Despite this, the results in the present study showed that this was the most underrepresented key textbook element. The inclusion of this element into future textbooks could lead to more effective comprehension and a

reduction in misconceptions held by students (Schroeder and Kucera 2022). Misconceptions regarding water vapour as a greenhouse gas and the greenhouse effect and climate change being a natural phenomenon require better representation in textbooks as the key elements used were lacking. Ultimately, textbooks should be written with common misconceptions in mind to diminish their prominence and better facilitate a climate literate society.
Keywords: misconceptions, climate literacy, key textbook elements, climate change, conceptual change

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Chapter 1: Introduction

1.1 Motivation

Present day society is faced with various environmental issues such as resource depletion, biodiversity loss, severe storm frequency, and many more with human induced climate change acting as the central force behind many of these events (Kuthe et al. 2019; Johnston 2019; Shepardson et al. 2010). Current methods of addressing this crisis are insufficient as primary climate forcers remain intact and are, in some cases, increasing (UNESCO 2014; IPCC 2022; NOAA 2022; Johnston 2019; Sheffers et al. 2016). There is a global desire to shift current values and approaches to make them more effective in combatting the climate crisis (United Nations 2014). This cannot be accomplished without integrating and promoting environmental education with a specific emphasis on climate change literacy (Cooper et al. 2019; United Nations 2014). A climate literate individual or public is more likely to possess increased tools and abilities to communicate, act, and critically think about climate change and the accompanying impacts (Choi at al. 2010; Kuthe et al. 2019; Metag et al. 2015; Hiramatsu et al. 2014; Cooper et al. 2019; CMEC 2010). This can then inform future laws and policies to actively combat climate change (Cooper et al. 2019). As such, it is vital that environmental education and climate literacy is a main focus going forward.

Misconceptions, incorrect ideas based on a lack of understanding or faulty thinking, associated with climate change are one factor that have the potential to hinder a climate literate society (Choi et al. 2010; Harrington 2013). Such misconceptions can prevent critical thinking, problem-solving, and alter the way new information is perceived (Choi et al. 2010; Pyc et al. 2014; Chang et al. 2015; Vosniadou 2020). Therefore, it is necessary that common climate change misconceptions are identified and considered by educators, authors, and students when environmental and climate education is being taught (Kuthe et al. 2019; Vosniadou 2020). Environmental science textbooks are one of the main resources within environmental education working to guide curriculums as well as expand on key concepts for both educators and students (Okeeffe 2012; Choi et al. 2010). As such, it is crucial that these textbooks are taking such misconceptions into consideration and presenting them in ways proven to be better at enhancing learning as well as combatting misconceptions through conceptual change (Kuthe et al. 2019;

Zaval and Cornwell 2017; Vosniadou 2020). This study examines introductory environmental science textbooks used in universities across Canada to determine the approaches being taken to address common climate change misconceptions.

1.2 Background

As climate change and its outcomes become more daunting, the need for meaningful action is heightened (Kuthe et al. 2019; Johnston 2019). Various international entities such as the United Nations Framework Convention on Climate Change (UNFCCC), Intergovernmental Panel on Climate Change (IPCC), and the United Nations Environment Programme (UNEP) have stressed the urgency and importance of climate actions through reports, targets, conferences, and agreements (United Nations 2014; Cooper et al. 2019; IPCC 2022). One method of facilitating this climate action that has been specifically emphasized by many of these entities is with environmental and climate education (Cooper et al. 2019; IPCC 2022).

Promoting and engaging the public in environmental education increases the chances of producing environmentally literate individuals (UNICEF 2018; NOAA 2009; Government of Canada 2002; Cooper et al. 2019). Environmental literacy, by definition, is "knowledge of environmental concepts and issues; the attitudinal dispositions, motivation, cognitive abilities, and skills, and the confidence and appropriate behaviours to apply such knowledge in order to make effective decisions in a range of environmental contexts" (NAAEE 2011). A key component within the scope of environmental education is climate change education and literacy specifically. This is defined as, "an understanding of your influence on climate and climate's influence on you and society" (NOAA 2009). Furthermore, a climate literate individual can understand key climate principles, assess climate information, meaningfully communicate about climate change, and acts informatively and responsibly in regards to climate issues (NOAA 2009). As such, environmental and climate education has the potential to contribute to the combative efforts against the climate crisis.

The integration of environmental education into school systems can assist people in becoming environmentally and climate literate (UNICEF 2018; NOAA 2009; Johnston 2019). Teaching environmental subject matter within schools can create a foundation of knowledge from which students can then expand upon and carry with them through their lifetime and future careers (UNICEF 2018). This will also expose the generation most impacted by climate change events to

necessary information and potentially enhance their relationship with the natural environment (Hopkins 2012; Kuthe et al. 2019).

Canada has been a global leader in environmental education programs and sustainability initiatives since the early stages (Hopkins 2012; Government of Canada 2002; CMEC 2010). The government recognized the importance of environmental education and education for sustainable development in 1987 and has worked to integrate it into both K-12 and higher education systems ever since (Hopkins 2012; Government of Canada 2002; CMEC 2010). Over the years, this education focus has evolved and taken on a bigger role in Canadian schools in an effort to prioritize environmentally literacy (Hopkins 2012).

While a main pillar of environmental education is hands-on, experiential learning, textbooks have a traditional role acting as a guide within classrooms and lectures (CMEC 2010; Choi 2010; Román and Busch 2015; Tippett 2010). These textbooks act as academic support for teachers to rely on as well as teach students and give them a more in depth look at concepts (Choi 2010; Román and Busch 2015). This is especially true in many environmental science classrooms as the educators do not always have strong backgrounds in environmental subject matter and, therefore, may require additional resources to depend upon (King 2010). As such, it is critical that these textbooks are providing accurate information in a manner that maximizes the ability to learn. One method to research and review textbook contents is content analysis and evaluative checklists (Jusuf 2018; Alharbi 2015; Weninger 2018; Guo et al. 2018). These methods allow for evaluation of textbook content and can point out shortcomings that may need to be further developed by authors (Okeeffe 2012; Tippett 2010).

Evidence shows that there are some textbook elements proven to enhance learning more than others (Nussbaum et al. 2018; Wyner and DeSalle 2020). Such elements include refutation texts, asking prompting questions, the use of figures and diagrams, and providing case studies or examples (Cooper et al. 2019; UNSW 2020; Nussbaum et al. 2018; Berkeley et al. 2015; Khine et al. 2016). While the inclusion of these elements has the capacity to better facilitate learning, they can also assist in combatting improper preconceived notions, or misconceptions, making them a critical component to include (Nussbaum et al. 2018). Textbook analysis can work to evaluate how well a certain text is addressing a misconception.

These improper preconceived notions, or misconceptions, can originate from past improper teaching or societal influences resulting in some students lacking a full understanding of

environmental concepts or having an incorrect perception of the concept all together (Vosniadou 2020). Misconceptions, especially those regarding science, can be hazardous as they spread misinformation and promote faulty ways of thinking (Vosniadou 2020). Many of the misconceptions in environmental science relate to climate change specifically (McCaffrey and Buhr 2008; Fortner 2001; Fleming et al. 2021; Román and Busch 2015). These improper views can then lead to people not believing in science resulting in a lack of action (Fleming et al. 2021; Román and Busch 2015). For example, when one does not believe climate change is occurring due to the fact that there is still cold weather or a snow storm event, they then do not act sustainably as they do not see a point (Fleming et al. 2021). Their improper way of thinking has the potential to spread to other members of society influencing their thoughts and actions. Due to the desperate need for action to tackle climate change, it is more important than ever that misconceptions are addressed and combatted in an effective matter that ultimately diminishes their presence in society.

1.3 Summary of Literature

There is a body of research documenting common climate change misconceptions among students as well as the general public as shown in Chapter three. However, there are much fewer studies evaluating the role textbooks play in either combatting or proliferating such misconceptions (Román and Busch 2015). One study that does aim to do this is Choi et al. (2010). This study performed a literature review to determine common climate change misconceptions then proceeded to evaluate several environmental science textbooks to analyze their approach to dealing with such misconceptions. Another similar study is one conducted by Román and Busch (2015) which analyzed middle-school textbooks' presentation of climate change concepts. The results from both studies show that there is a clear correlation between the material taught in textbooks and students' beliefs and perceptions of the environment. A number of studies also analyze scientific textbooks through the use of content analysis, evaluative checklists, and qualitative and quantitative analysis of themes to determine their role in communicating environmental science topics (Wyner and DeSalle 2020; Navarro-Diaz 2020; Biström 2021, Manouchehrizadeh 2019). While they do not specifically consider misconceptions, the methods of analysis and results are relevant to this study.

Despite this research, there continues to be literature gaps regarding this specific area. There is a lack of recent studies surrounding the presentation of common climate change misconceptions in current introductory environmental science textbooks as the only very similar

one found analyzed textbooks published from 2002-2006. Furthermore, much of the literature reviewed showed studies that were conducted on elementary to middle school levels with some, but few, including high schools and undergraduate programs.

1.4 Study Introduction and Summary of Approach

The present study involves the consultation of literature to determine current prominent climate change misconceptions which will then inform an evaluation of environmental science textbooks currently used across introductory university level courses in Canada with the main objective of determining their approach to these misconceptions. This study is guided by the central research question of, "*To what degree are environmental science textbooks used in introductory courses at the top 15 research universities in Canada including textbook elements proven to enhance learning with respect to prominent climate change misconceptions?"*. By researching this topic, the objectives are to A) determine common climate change misconceptions based on up to date, peer-reviewed literature, B) investigate the approaches textbooks are using to combat misconceptions, if any, and C) discuss the implications of the results to suggest possible areas of improvement.

The study will consult commonly used university level environmental science textbooks used in first year introductory environmental science courses. The textbooks are taken from the list of U15 universities which are located in seven different provinces across Canada (Figure 1.1). This list is an association of the top research universities in Canada with an aim to advance knowledge and innovation through their programs (U15 n.d.). Within these textbooks, the chapters regarding climate change or other closely related topics to the identified misconceptions, such as the atmospheric science chapters, will be analyzed rather than the entire textbook.

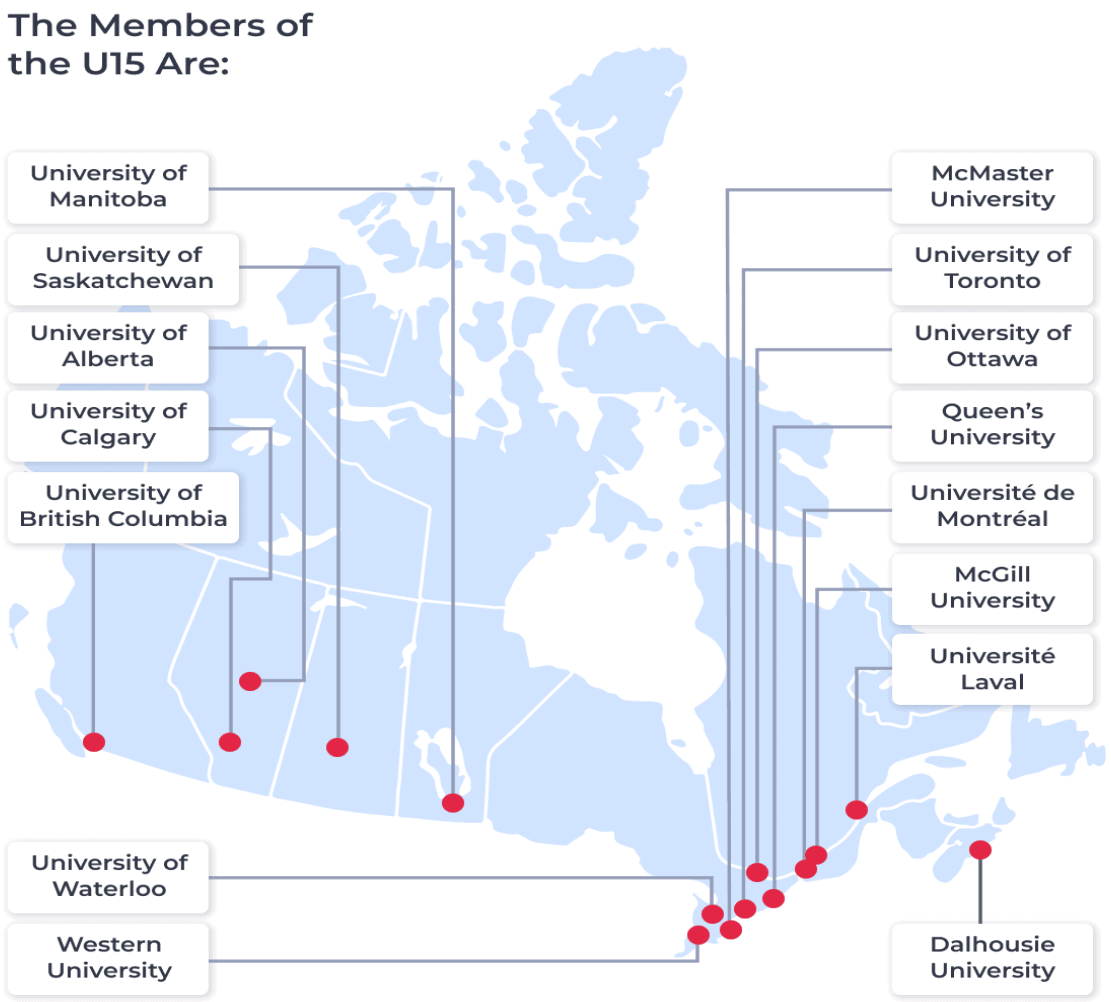


Figure 1.1. A map displaying the location and names of the U15 members involved in this study (U15 n.d.).

To address the research question and accomplish these objectives, a literature review will be conducted to determine two key components of the study. First, the most common misconceptions pertaining to climate change. Second, textbook elements that assist the reader's comprehension of the material and facilitate learning, especially with respect to correcting misconceptions. The chapters on climate change and atmospheric science will then be read to determine the approaches being taken to address the common climate change misconceptions. During each read through, an evaluative checklist will be used containing the six misconceptions and the five textbook elements. Each time the textbook uses one of these elements in relation to

the explanation of a misconception will be noted, and the associated segment of text relating to each approach will be recorded.

From here, information and results are produced that may assist authors in composing future textbooks and, ultimately, bring university environmental science programs one step closer to being of the highest possible quality. In addition, this study can contribute to diminishing the frequency and prominence of climate change misconceptions within society giving people a better skill set to combat climate change.

Chapter 2: Literature Review

2.1 Literature Review Introduction

This literature review will discuss the evolution of climate change and the impacts it is having on areas within Canada. The state of environmental education on a broader scale will be reviewed before limiting the scope to environmental education and climate literacy. This review will outline how misconceptions arise, what their impacts are, and which are the most common ones related to climate change. The role textbooks take on within an educational setting as well as how to analyze them to ensure they are effective in learning and conceptual change is provided before stating which elements can assist in increasing their effectiveness.

Knowledge gaps within the literature will also be identified and further discussed before stating concluding remarks. Contributing to the information within this literature review were various textbooks, scientific journals, curriculums, books, United Nations proceedings, and news articles.

2.2 Climate Change

2.2.1 The Evolution of Climate Change Research

Climate change is a natural phenomenon, but during the early to mid 1900's, the concept of accelerated climate change was explored after a variety of people observed shifts in weather and climate events (Weart 2003; Weart 2008). This prompted further studies resulting in the development of climate theories, models, and environmentally focused international collaborations such as the Intergovernmental Panel on Climate Change (Weart 2003; Weart 2008; Edwards 2010; IPCC 2022). Climate change continues to be studied presently on a large scale with peer-reviewed literature across many disciplines, climate change journals, news exposure, research funding, and public interest growing exponentially (Griensisen and Zhang 2011). Furthermore, many academic institutions have expanded their scope to include climate change research reinforcing this notion (Griensisen and Zhang 2011). Ultimately, since the discovery of rapid climate change in the 20th century, climate change research and interest in various disciplines has increased on an international level.

2.2.2 Anthropogenic Forces on Climate Change

One of the results of this focus on climate change research was an understanding that anthropogenic factors are responsible for this unprecedented rate of climatic change (Weart 2003; Weart 2008; Martinez 2005). The Industrial Revolution was responsible for large-scale technological advancements and population growth resulting in a drastic increase in greenhouse

gas emissions leaving levels of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) much higher than they were prior to 1750 (Martinez 2005; Siddik et al. 2010; Hay 2016; Dietz et al. 2007). Since then, greenhouse gases continued to be emitted by a range of human activities and have enhanced the greenhouse effect which has resulted in an approximate 1.0 degree Celsius increase in global temperatures and will lead to further increases if these emission rates continue (IPCC 2018; Jain 2003). These incretions are subjecting the natural environment and human societies, especially vulnerable populations, to devasting impacts that can be observed across the globe (Bell et al. 2021; Lorenzoni 2006; Benevolenza and DeRigne 2018).

2.2.3 The Impacts of Climate Change in Canada

Canada is not excluded from these impacts as the effects of climate change are being observed in various areas across the nation. The amount of water available for a region, or water yields, is shifting due to evapotranspiration increasing in Western and Northeast Canada and precipitation increasing in South central and East Canada (Li and Wang 2021). Winter temperatures have been increasing in Quebec over the span of several decades resulting in an increase in flooding (Ouellet et al. 2012). Average temperatures in south central Canada (Ontario and Quebec) have been increasing which, in turn, increases the likelihood of freezing rain events happening in the area during December to February (Cheng et al. 2007). The Canadian Arctic is particularly impacted as changes are occurring at an accelerated rate compared to other locations (O'Rourke 2017; Vogel and Bullock 2020). The increased frequency and intensity of severe storms is resulting in elevated erosion rates degrading coastal zones (O'Rourke 2017). While this has sociopolitical implications, there are also strong cultural implications (Vogel and Bullock 2020). While these are just a few examples, all provinces in Canada are experiencing events that can be linked to climate change.

2.3 Environmental Education

2.3.1 Importance of Environmental Education

As climate change impacts worsen, research surrounding it grows, and it is integrated more into everyday life, people must be equipped with the appropriate knowledge, skills, and tools; one method of doing this is through environmental education (Stevenson et al. 2013; Thomson et al. 2010). While climate change will impact countries, and even individual communities, disproportionately, environmental education is a responsibility shared by all globally (Lang 2014). Implementation of environmental education can nurture and strengthen the skills needed

to combat climate change while increasing the public's increased awareness, sensibility, and understanding of the climate crisis along with its accompanying issues (Stevenson et al. 2013). The internationally agreed upon objectives for environmental education include "helping social groups and individuals acquire the skills for identifying and solving environmental problems" (Thomson et al. 2010). Furthermore, the United Nations (2014) states that environmental education works to shape individuals into being able to critically think about these problems from a multidisciplinary perspective. Ultimately, environmental education can have a large impact on the climate crisis as it teaches crucial concepts, promotes a relationship between people and the natural world, and increases the likelihood of people identifying solutions for environmental issues.

2.3.2: Gaps in Canadian Environmental Education

Canada, in particular, has recognized the importance of environmental education and has taken many years to integrate and develop it within school systems (Hart 1990). However, there are many areas that remain insufficient and require further development. After a large-scale review of Canadian curriculum objectives, it was determined that there were many gaps present such as the exclusion of field trips and low levels of primary education regarding environment education (Mustafa 2018). There are few nation-wide organizations or systems for environmental education in Canada which hinders the ability of interested parties, such as governments or educators, to communicate on a regular basis (Towler and Francis 2014). Additionally, there is a lack of federal involvement for environmental education as education falls under provincial management and jurisdiction leading to a lack of federal funding and oversight reducing widespread collaboration (Towler and Francis 2014). When surveying educators in particular, it was found that there is uncertainty around environmental education learning objectives as well as how to measure success in achieving them (Thomson et al. 2010; Castleden 2020). While environmental education has come a long way in Canada since its inception, there is more work required before we can conclude that an effective system is in place across all provinces.

2.3.3: Climate Literacy

While there are many critical aspects of environmental education, climate literacy in particular is a crucial component in combatting the climate crisis. When people possess an in depth understanding of climate change, it greatly reduces their vulnerability to climate issues as well as allows them to widely disseminate knowledge into the general public (NOAA 2009). A

climate literate public is then able take climate change into account and make better informed decisions, ultimately producing more effective and accepted policy, actions, and decisions with respect to climate change (Johnston 2019; Helbling et al. 2021). Despite the vitality of climate literacy, there are many areas where it remains low and requires improvement as previously noted with environmental education. Azevedo (2017) found that climate misconceptions as well as climate change skepticism remains high especially within developing countries despite the urge for more climate literate societies. When examining the preconceived notions of teenagers, it was discovered that there was a considerable differences in the accuracy of their knowledge regarding climate change (Kuthe et al. 2019). During a large-scale evaluation of Canadian university syllabi, it was determined that fewer than 10% of the material taught was regarding climate change and climate literacy in particular (Cooper et al. 2019). While a climate literate public is especially important in present times, there is much evidence to suggest many areas of it in education systems require attention and further development in order for this to be achieved.

2.4: Misconceptions on a Broad Scale

Misconceptions, improper ideas based on a lack of understanding or faulty thinking, can arise from a variety of reasons including social experiences, misunderstandings, improper teaching, and media exposure (Pyc et al. 2014; Graham et al. 2012). However, there are actions that can be taken in an educational setting such as understanding students' backgrounds, challenging their way of thinking, and directly addressing their misconceptions to both prevent and correct such misconceptions (Barke et al. 2009; Gomez-Zwiep 2006). Whichever method of addressing misconceptions is used, the educator must understand conceptual change models and the process involved in shifting one's ideas and thought processes (Chi and Roscoe 2002; Goris and Dyrenfurth 2010).

2.4.1 The Impact of Misconceptions in Science

It is critical that misconceptions are addressed as they can hinder students' ability to fully understand scientific concepts and, therefore, can reduce the effectiveness of education. Preconceived misconceptions typically contradict current scientific understanding of a concept or topic and can alter the way one interprets and analyzes information that is new to them (Pyc et al. 2014; Goris and Dyrenfurth 2010). Furthermore, misconceptions can disconnect people from the true concepts removing them even further from an accurate understanding (Pyc et al. 2014). It is not only students' misconceptions that can act as a barrier in education, but also the

misconceptions teachers hold as they hinder proper scientific fact that can provide students with biased or faulty information (Menz et al. 2021). Therefore, it is important for misconceptions to be addressed at all levels within educational settings.

2.4.2 Climate Change Misconceptions in Environmental Science

Many of the misconceptions present in environmental science, in particular, across all levels of school, including K-12 as well as post-secondary, are concerning climate change (McCaffrey and Buhr 2008; Fortner 2001; Fleming et al. 2021; Román and Busch 2015). Chang et al. (2015) state that multiple studies show grade nines' foundational knowledge of climate change is inaccurate and influencing their abilities to understand in depth material on the subject. Furthermore, there is wide spread agreement in the scientific community that there are multiple misconceptions related to the causes and risks of climate change (McCaffrey and Buhr 2008; Fortner 2001). Fleming et al. (2021) conducted a literature review which determined that not only are these climate change misconceptions prominent, but they are also resilient and not easily corrected. The high frequency as well as resilience of such misconceptions in both students and teachers indicate that addressing them should be prioritized in the education system.

2.5 Commonly Held Climate Change Misconceptions

2.5.1 Weather and Climate

One of the most common misconceptions associated with climate change is that there is no difference between climate and weather. Several in-depth literature reviews found that many students, teachers and the public hold the belief that weather and climate are the same (Choi et al. 2010, McCaffrey and Buhr 2008, Lombardi and Sinatra 2012, and Nussbaum et al. 2018). This has further implications as it leads to the belief that climate is simply long term weather and cannot be predicted, so climate change is not a concern (McCaffrey and Buhr 2008). In addition to various literature reviews, studies with undergraduate students were also conducted to determine that there is a lack of understanding when it comes to the difference between weather and climate (Rebich and Gautier 2005; Gautier et al. 2018). This combination of literature reviews and studies allows for the conclusion that this is a prominent climate change misconception.

2.5.2 Ozone Layer Role

Another commonly held misconception is that the ozone layer plays a primary role in causing climate change. Both Fortner (2001) and Papadimitriou (2004) conducted two separate survey

based studies where the results showed that over 50% of students believed the ozone layer was responsible for global warming. After conducting a series of interviews, Chang and Pascua (2015) as well as Fleming et al. (2021) found that the most frequent misconception was that ozone layer depletion is responsible for climate change. The prominence of this misconception was reinforced through several literature reviews which determined the majority of students believed the hole in the ozone layer allowed for additional UV rays to enter the atmosphere ultimately warming the planet (Choi et al. 2010; McCaffrey and Buhr 2008; Boon 2010, and Nussbaum et al. 2018). McCuin et al. (2018) administered pre and post-tests to first year undergraduate students which revealed that many held incorrect understandings of the ozone layer's role in the greenhouse effect. Ultimately, the abundance of literature related to this misconception supports the idea that this is the most prominent climate change misconception held among students and the general public.

2.5.3 The Relationship Between Pollution and Climate Change

The literature indicates that there is a wide spread, incorrect belief that any type of general pollution can result in climate change. Choi et al. (2010) found that middle and high school students believe global warming and climate change can arise as a direct result of littering and general environmental pollution such as nutrient leaching in lakes for example. Again, literature reviews concluded that many believed that acid rain, spray cans, any type of air pollution is able to cause global warming (Shepardson et al. 2010; Boon 2010; Lombardi and Sinatra 2012). The previously mentioned studies (interviews, tests, surveys) done by Papadimitriou (2004), Chang and Pascua (2015), Fleming et al. (2021), and McCuin et al. (2018) had similar results. Ultimately, many students associated unrelated environmental issues with being a factor in the enhancement of the greenhouse effect and climate change events making it a more prominent misconception.

2.5.4 The Natural Greenhouse Effect

Another well documented misconception regards the greenhouse effect, along with climate change, being completely human caused with no natural component. A combination of the forementioned literature reviews by McCaffrey and Buhr (2008), Nussbaum et al. (2018), and Rebich and Gautier (2005) and studies by McCuin et al. (2018), Fleming et al. (2021), and Chang and Pascua (2015) concluded that students and the general public hold this

misconception. Their research highlights the incorrect understanding of the greenhouse effect, the influences on it, and its role in changing the climate naturally.

2.5.5 Outlier Weather Events

The fifth misconception stems from the confusion about the difference between weather and climate as many people believe one outlier weather event, such as a warm day in winter or a severe hurricane, can be attributed to climate change. McCaffrey and Buhr (2008), Nussbaum et al. (2018), Choi et al. (2010), Fleming et al. (2021), and Papadimitriou (2004) have all concluded that many people observe one unusual weather event and definitively state that climate change is the cause. However, this understanding is based on a lack of understanding of the difference between weather and climate and must be further addressed.

2.5.6 Water Vapour as a Greenhouse Gas

While appearing the least amount of times in the literature, it was stated that there is a common belief that water vapour is not a greenhouse gas and has no impact on climate. The literature reviews from Choi et al. (2010), McCuin et al. (2018), and Boon (2010) found that students either do not consider this gas or do not understand the role it plays in the atmosphere Chang and Pascua's (2015) interview study also found that this is the case as it was reported numerous times.

2.6 Textbooks in Educational Settings

2.6.1 The Role of Textbooks

Many teachers responsible for teaching environmental based subject matter, especially where climate change is concerned, do not have a strong background in it and, as such, have to rely on textbooks (Okeeffe 2012; Choi et al. 2010). Fortner (2001) performed a survey on teachers where their results showed that teachers reported their own knowledge regarding climate change to be relatively low. While there are various materials available to educators that can be used to teach environmental science, textbooks are still the overwhelmingly most relied on resource in the classroom (Choi et al. 2010). When King surveyed 150 teachers, the majority had insufficient backgrounds in earth and environmental science content and fully relied on textbooks for in depth subject matter (2010). Not only are these textbooks used to expand on the material, but they also act as a guide for educators to develop curriculum and identify key concepts (Okeeffe 2012). In many cases, educators either lack a foundation of environment

science concepts or share similar misconceptions to their students. As such, textbooks are a crucial component in the classroom setting and are heavily relied upon to facilitate learning.

2.6.2 Analyzing Textbooks

Textbook evaluation is a vital component of curriculum development and student comprehension. There have been different textbook analyses methods used to evaluate the effectiveness of such textbooks. As textbooks are a key component in many classrooms, textbook analyses have been conducted since 900 AD to ensure the effectiveness and accuracy of them as well as make necessary revisions (Okeeffe 2012; Fan 2013).

2.6.3 Textbook Analysis Methodology

There are different practices that can be applied to evaluate textbooks; common ones involve the coding for and identification of select terms and phrases while another is the use of evaluative checklists (Jusuf 2018; Alharbi 2015; Weninger 2018; Guo et al. 2018). Widely used checklists for textbook analysis were developed and tested in several studies including Daoud and Celce-Murcia 1979, Sarem et al. 2013, Karamoozian 2003, Cunningsworth 1995, and Sheldon 1988. Such checklists were used to code for select content within textbooks which informed researchers on their probable effectiveness in teaching the subject matter. Many of these checklists continue to be used in various textbook analysis studies. AbdelWahab (2013) stated the commonality of these checklists and tested a pre-developed checklist for its effectiveness in analyzing textbooks, ultimately determining that it was sufficient. Tshuma and Sanders (2015) performed a content analysis using an evaluative checklist where segmented phrases and sentences were also recorded when checkmarks were given. In the Chang and Pascua (2015) study, a content analysis acted as the main method where the observed themes and similarities among the text were segmented and noted. Guo et al. (2018) hand coded for figures and diagrams to determine which were the most common among the textbooks as well as how this may influence comprehension. In conclusion, there are many studies that have developed and used such evaluative checklists to analyze textbooks. Coding for and noting key terms and phrases is another commonly practiced method.

2.7 Key Textbook Elements

2.7.1 Figures and Diagrams

There are various textbook elements capable of enhancing learning while also combatting misconceptions; one of these elements is the use of figures and diagrams. Figures and diagrams

allow the author to represent data in a way that is easier to comprehend especially when the data cannot be expressed in any other way (Evagorou et al. 2015). There is a large amount of evidence indicating the benefits of having media such as figures and diagrams present in textbooks to better facilitate student learning (Carney and Levin 2002; Berkeley et al. 2015). Khine et al. (2016) found that when students are able to visualize data presented to them, it enhances comprehension and facilitates conceptual learning. As conceptual learning is key in combatting misconceptions, the inclusion of this element in textbooks is critical. Students' conceptual change through textbooks with well-formed illustrations versus those without was examined and it was determined that the inclusion of such elements enhances conceptual learning (Cheng et al. 2014; Khine 2013). Through such research, many have found that figures and diagrams can assist students in learning concepts as well as conceptual change in particular.

2.7.2 Case Studies and Examples

The inclusion of case studies and examples within textbooks is another way to enhance student learning and concepts more comprehendible. Case studies allow students to apply developed critical thinking to real life situations (UNSW 2020). This exposes them to the reality of the situation increasing the likelihood of one to take effective action on issues (UNSW 2020). Additionally, when examples are used during the presentation of concepts, they help to better engage the students (SERC 2021). Seshan et al. (2021) conducted a study with undergraduate students and determined that the inclusion of case studies in textbooks improves knowledge development, critical thinking, problem solving, communication skills, and collaboration. In terms of case studies and examples correcting misconceptions specifically, textbooks that take background knowledge and interests into account are more likely to allow for conceptual learning (Khine 2013). Therefore, by including case studies and examples within textbooks, students are able to better comprehend the material as well as shift their incorrect understandings ultimately correcting their misconceptions.

2.7.3 Refuting Misconceptions

Another key textbook element that works to correct misconceptions and help learning is when the misconceptions are directly addressed by the text. Nussbaum et al.'s (2018) study tested the effectiveness of this element, specifically with climate change misconceptions, using pre and post-tests where the results revealed it is effective in combatting these misconceptions even the resilient ones. Ariasi and Mason (2011) had similar results with their study that tracked

eye movements to determine whether refutational or non-refutational texts had more success in combatting climate change misconceptions. If the eye movement was faster, comprehension was determined to be faster and easier and vice versa. Additionally, Ferrero et al. (2020) and Aguilar et al. (2020) determined that refutation texts are effective when attempting to correct even prominent or resilient misconceptions. While there are many elements that simply enhance learning, the literature has indicated that addressing misconceptions directly is the most effective way to promote conceptual change ultimately diminishing misconceptions.

2.7.4 Explaining the Concept

For common misconceptions to be reduced, textbooks must include and explain the concepts they are associated with. The previously mentioned papers by Ariasi and Mason (2011), Choi et al. (2010), Tshuma and Sanders (2015), and Berkeley et al. (2015) have all stated the importance of including these concepts as a means of diminishing prominent misconceptions. If the content related to common climate change misconceptions is omitted from textbooks, they will go unaddressed and likely persist as well as become more resilient.

2.7.5 Prompting Questions

The final textbook element found by this review regards the use of prompting questions as a method of gauging student understanding. The inclusion of questions throughout textbooks allows students to challenge their own knowledge which can promote conceptual change and correct misconceptions (Nussbaum et al. 2018). Berkeley et al. (2015) also outlines the impact asking questions can have on diminishing misconceptions. When such questions are included in textbooks, it enhances learning and allows for preconceived notions to be challenged and rethought.

2.7.6 Integrating Key Elements Into Textbooks

As there are certain textbook elements that can work to enhance learning and combat misconceptions, it is crucial authors are aware of common misconceptions at the time the books are written so that they can be adequately addressed. Students' preconceived notions and prior knowledge influence how they perceive incoming information also highlighting the importance of designing educational materials with common misconceptions in mind (Vosniadou 2020; Tshuma and Sanders 2015). Choi et al. (2010) goes on to say if students' conceptual development is to be facilitated, prominent climate change misconceptions must be reviewed by authors and they must integrate tools to combat them in their work. Despite these claims, current

middle school and high school environmental science textbooks are not adequately working to correct misconceptions. When seven environmental science textbooks used in middle and high school classrooms were assessed by Choi et al. (2010), it was found that they do not adequately address the most prevalent climate change misconceptions. Therefore, students are not receiving the full benefits of the material being provided within them. Furthermore, a review of 29 widely used high school science textbooks in England and Wales revealed that there was a severe lack of inclusion of environmental and earth science topics within them (King 2010). Ultimately, there is evidence to suggest that textbooks have not taken misconceptions into account and, therefore, have not actively included helpful elements. However, similar studies are outdated considering the rate at which textbooks are updated highlighting the need for a more current study to be conducted.

2.8 Gaps in the Literature

While there is documentation on which climate misconceptions are commonly held by middle and high school students, there is a gap regarding how they are represented and dealt with within these textbooks (Choi et al. 2010). This issue is rooted in the lack of understanding surrounding which methods are most effective in combatting misconceptions resulting in them being poorly addressed in textbooks (Mayer 2011). Another contributing factor to this gap is that many textbooks have not been analyzed to observe how they are addressing such misconceptions (King 2010). This can lead to thousands of teachers using textbooks that may not prove to be the most effective.

Furthermore, the only similar studies found were conducted in 2010 and 2015 which is a long time period considering the fast rate at which environmental issues are changing and textbooks are being updated. As such, this study provides insight on the changes to textbooks, if any, that have been made in regards to misconceptions since these studies have been published. It will also add to the little research that has been done on this subject matter.

2.9 Literature Review Conclusion

This literature review has outlined several topics relevant to this study such as climate change, environmental education, misconceptions, textbooks in education and textbook elements, and the knowledge gaps present. The information presented within these topics has worked to provide the background knowledge necessary for the content this study portrays. The necessity for environmental education and a climate literate public has been emphasised. The

most prominent misconceptions related to climate change have been identified. Furthermore, methods used to analyze textbooks and key textbook elements that allow for enhanced learning have been well documented.

In summary, climate change is becoming an increasingly important topic within various disciplines as knowledge on it expands and its risk to humanity increases. Environmental education with a particular focus on climate literacy is a crucial component in combatting this climate crisis and, as such, has to continue to be developed and facilitated. Misconceptions are a large-scale problem that threaten the fight against this crisis, with those concerning climate change being particularly prominent among both students and teachers. However, there are many ways textbooks can diminish the likelihood that climate change misconceptions persist, but they require further study and considerations by authors. Finally, additional research is required regarding how currently used environmental science textbooks are presenting information linked to common climate change misconceptions to fill existing knowledge gaps.

Chapter 3: Methods

3.1 – Part One: Literature Review

A literature review was conducted to determine two main components of the present study: current common climate change misconceptions and key textbook elements that have the capacity to enhance learning and combat misconceptions. Both searches were conducted using three main search engines including Google Scholar, Dalhousie Novanet, and Education Resources Information Center (ERIC). A number of journal articles and educational frameworks were consulted. Both searches continued until the referenced studies became repetitive with what had already been found.

3.1.1 – Identifying Misconceptions

A combination of several key words were used in the search to identify common climate change misconceptions: environmental science, climate change, misconceptions, alternative conceptions, greenhouse effect, global warming, conceptual learning, atmospheric science, greenhouse gases, student understanding, climate literacy, and student learning. Any misconception that appeared more than four times in the literature was used within the study.

3.1.2 – Identifying Textbook Elements

A combination of the following key words were used to determine the textbook elements: misconceptions, alternative conceptions, diminishing misconceptions, combatting misconceptions, textbook techniques, textbook elements, textbook strategies, textbook characteristics. Any element that appeared more than three times within the literature was used within the study.

3.2 – Part Two: Textbook Analysis

3.2.1 – Study Sample

The sample for this study was limited to the textbooks used within introductory environmental science courses at the 15 universities in Canada listed on the U15 list. The textbooks were determined by locating the most recent version of the course syllabus either online or through contacting the university directly. The oldest syllabus consulted was one from the spring semester in 2019 with the most recent one being from the winter semester of 2023. However, not all universities used the most recent edition of the textbook available so, in addition to the edition being used, the newest edition was also included in the study to allow for further comparison. There were five universities omitted from this study as three stated they do

not use textbooks within their classrooms and two schools use French as their primary language. In total, there were nine textbooks analyzed with eight of them currently being used within the universities and one being the newest edition available, but not currently in use (Table 3.1). As the misconceptions directly relate to climate change, only the climate change chapters and closely related chapters were examined within each textbook. The atmospheric science chapter was determined to be closely related as many of the misconceptions pertained to the content presented within this chapter.

Table 3.1. Each member of the U15 list along with the edition of the textbook currently used within their classroom and the most recent edition of the textbook published.

University	**Textbook Edition Used**	**Most Recent Textbook Edition Available**
University of Manitoba	Berg LR, Hagar MC, Goodman LG, Baydack R. 2010. Visualizing the Environment. Canadian Edition. John Wiley & Sons.	Berg LR, Hagar MC, Goodman LG, Baydack R. 2010. Visualizing the Environment. Canadian Edition. John Wiley & Sons.
University of Waterloo	Withgott J, Laposata M, Murck B. 2017. Environment: The Science Behind the Stories. 3rd Canadian Edition. Pearson Canada.	Withgott J, Laposata M. 2021. Environment: The Science Behind the Stories. 7th Edition. Pearson.
University of Toronto	Withgott J, Laposata M, Murck B. 2017. Environment: The Science Behind the Stories. 3rd Canadian Edition. Pearson Canada.	Withgott J, Laposata M. 2021. Environment: The Science Behind the Stories. 7th Edition. Pearson.
Dalhousie University	Karr S, Houtman A, Interlandi J. 2021. Environmental Science for a changing world. 4th Edition. Freeman & Co.	Karr S, Houtman A, Interlandi J. 2021. Environmental Science for a changing world. 4th Edition. Freeman & Co.
University of Calgary	Dearden P, Mitchell B, and O'Connell E. 2020. Environmental Change and Challenge. A Canadian Perspective. Oxford University Press.	Dearden P, Mitchell B, and O'Connell E. 2020. Environmental Change and Challenge. A Canadian Perspective. Oxford University Press.
University of Ottawa	Molles M, Borrell B. 2016.	Molles M, Borrell B. 2016.

	Environment, science, issues, solutions. 1st Edition. W.H. Freeman Company. Withgott J, Brennan B, Murck B. 2013. Environment: The science behind the stories. 2nd Canadian Edition. Pearson.	Environment, science, issues, solutions. 1st Edition. W.H. Freeman Company. Withgott J, Laposata M. 2021. Environment: The Science Behind the Stories. 7th Edition. Pearson.
University of British Columbia	Withgott J, Laposata M, Murck B. 2017. Environment: The Science Behind the Stories. 3rd Canadian Edition. Pearson Canada.	Withgott J, Laposata M. 2021. Environment: The Science Behind the Stories. 7th Edition. Pearson.
University of Alberta	Fisher M. 2019. Environmental Biology. 1st Edition. Open Oregon Educational Resources.	Fisher M. 2019. Environmental Biology. 1st Edition. Open Oregon Educational Resources.
Queen's University	N/A	N/A
University of Saskatchewan	N/A	N/A
McGill University	N/A	N/A
McMaster University	N/A	N/A
Western University	N/A	N/A

3.2.2 – Data Collection

An evaluative checklist was used for the purposes of this study similar to many others as outlined in chapter two (Jusuf 2018; Alharbi 2015; Weninger 2018; Guo et al. 2018; Celce-Murcia 1979; Sarem et al. 2013; Karamoozian 2003; Cunningsworth 1995; Sheldon 1988; AbdelWahab 2013; Chang and Pascua 2015). This checklist contained the six misconceptions as well as the five key textbooks elements of presence of the concept, refutes misconception, uses figures and diagrams, provides case studies and examples, and asks questions. Each climate change and atmospheric science chapter from each textbook were read several times and textbook elements that were present were recorded in the checklist.

Similar to Tshuma and Sanders (2015), each time a checkmark was given for an element, a record of which segment or phrase that prompted the checkmark was noted in a Microsoft

Excel spreadsheet (Table 3.2). For example, if when dealing with the misconception that there is no difference between climate change and weather, the textbook stated the definition of each using the phrases, "short-term" and "long-term" to do so, this would be recorded. This type of record was kept for each of the textbook elements with the exception of the figures and diagrams (Table 3.2). There were seven sub-categories figures and diagrams could be labelled as including pictures, maps, timelines, flow-diagrams, tables, graphs, and other similar to the approach by Guo et al. (2018) (Table 3.2). If the figure/diagram was labelled as a graph, the type of graph was also recorded. This allowed for further analysis and comparison of the texts.

Table 3.2 The textbook element along with the content that was recorded if it was present within a textbook.

Textbook Element	**Content Recorded**
Presence of Concept	Yes/No; Key words and phrases
Misconception Refutation	Yes/No; Key words and phrases
Figures and Diagrams	Yes/No; Diagram type; what the diagram captures
Examples and Case Studies	Yes/No; Whether it's an example or case study; description of key elements such as time, place, event
Prompting Questions	Yes/No; general topic of question

3.2.3 Data Analysis

Once each textbook was reviewed enough times that allowed for the completion of the checklists and the Excel log of key words and phrases, the log was analyzed. The sum of the number of times each element was used across the textbooks was calculated. A breakdown of the number of times an element was used per book was also included in the analysis. All observed similarities and differences between which elements were used for which misconception in each textbook were stated as well as any outlier data. For example, if all textbooks except for one used the example of a greenhouse when explaining the greenhouse effect, this was noted. The number of textbooks that used certain language or themes was also recorded. A comparison of the common and different themes, words, quotes, phrases, and figures/diagrams was then completed.

3.3 – Reliability and Validity

When considering the reliability of the study, the evaluative checklist was developed through a literature review that stated some of the most common climate change misconceptions as well as textbook elements that assist with comprehension. As this checklist was then used to check for the presence or absence of an element, this is an objective component that would likely

produce the same result if repeated. However, it should be noted that the main criticism stated for the checklist method is that subjectivity cannot be entirely removed and, therefore, can produce different results depending on the study (Karamoozian 2008; Sarem et al. 2013). For example, when recording key phrases, personal opinion and prior knowledge of the researcher could have influenced if certain content was deemed relevant to the misconception or not.

In regards to validity, all misconceptions and textbook elements were derived from the literature as stated in Tables 4.1 and 4.2. According to AbdelWahab (2013), a literature review is one of three methods that can be used to create an evaluative checklist used for textbook analyses increasing the validity. Evaluating each misconception in terms of which elements are used to present them in each textbook will answer the degree to which key elements are included when presenting misconceptions.

3.4 Limitations and Delimitations

One limitation of this study is the subjectivity of the evaluative checklist method. While there were measures taken to reduce this such as basing all methods on the literature as well as recording the terms that allowed for a checkmark, it has been stated that this method of textbook analysis cannot be free of all subjectivity. As such, the answers may differ depending on the views of the researcher and the study itself. Another limitation of the study was that some of the most recent syllabi were unable to be located resulting in the use of syllabi dating back to the spring semester of 2019. However, measures were taken to minimize this possible limitation as the most recent version of each textbook was also analyzed.

In terms of the delimitations of the study, two universities, Université Laval and Université de Montreal, were omitted from the study due to a language barrier. Upon reviewing their syllabi, it was determined that both textbooks used were in French and therefore, due to the limited skills of the researcher, could not be analyzed. Additionally, only the climate change and atmospheric chapters were read as many of the misconceptions pertained to this information. However, environmental issues are heavily interconnected meaning additional relevant content or elements could have been located in other chapters, but were not considered.

Chapter 4: Results

4.1 – Part One: Literature Review

4.1.1 – Identifying Misconceptions

The literature review produced six commonly held climate change misconceptions from a variety of literature reviews and empirical studies (Table 4.1; Appendix Table A).

Table 4.1. The six most commonly held climate change misconceptions based on the literature along with their associated reference.

Misconception	Reference
1. There is no difference between climate and weather.	Choi et al. 2010 Lombardi and Sinatra 2012 Nussbaum et al. 2018 Rebich and Gautier 2005 Fleming et al. 2021 Gautier et al. 2018
2. The hole in the ozone layer is primarily responsible for climate change and global warming.	Boon 2010 Choi et al. 2010 Chang and Pascua 2015 McCuin et al. 2018 McCaffrey and Buhr 2008 Fortner 2001 Papadimitriou 2004 Nussbaum et al. 2018 Fleming et al. 2021
3. Incorrect understanding of the relationship between pollution and climate change.	Choi et al. 2010 Shepardson et al. 2010 Lombardi and Sinatra 2012 Papadimitriou 2004 Chang and Pascua 2015 Boon 2010 McCuin et al. 2018 Fleming et al. 2021 Román and Busch 2015 Varela et al. 2018
4. The greenhouse effect is not a natural phenomenon and is caused by human actions.	McCaffrey and Buhr 2008 Rebich and Gautier 2005 Nussbaum et al. 2018 McCuin et al. 2018 Fleming et al. 2021

	Chang and Pascua 2015 Román and Busch 2015
5. Outlier weather events such as a snow storm or one warm day during winter can indicate the state of climate change.	McCaffrey and Buhr 2008 Nussbaum et al. 2018 Choi et al. 2010 Fleming et al. 2021 Papadimitriou 2004
6. Water vapour is not a greenhouse gas.	Choi et al. 2010 Boon 2010 Chang and Pascua 2015 McCuin et al. 2018

4.1.2 – Identifying Textbook Elements

This search produced the following five textbook elements that are shown to assist with comprehension: 1. explaining the concept related to the misconception, 2. Refuting the misconception, 3. the use of figures and diagrams, 4. the use of case studies and examples, and 5. the use of prompting questions to gauge understanding (Table 4.2).

Table 4.2. Textbook elements that assist with student learning from textbooks along with how they are defined in the context of this study and the literature sources they were derived from.

Textbook Element	Definition	Reference
Concept Explanation	Content related to the misconception is included and explained.	Ariasi and Mason 2011 Choi et al. 2010 Tshuma and Sanders 2015 Berkeley et al. 2015
Misconception Refutation	The text directly states that there is a misconception and provides an explanation as to why it is incorrect.	Nussbaum et al. 2018 Ariasi and Mason 2011 Tshuma and Sanders 2015 Ferrero et al. 2020 Vosniadou 2020 Choi et al. 2010 Dole 2011 Tippett 2010 Bråten et al. 2022
Figures and Diagrams	A figure is any type of graph while a diagram refers to a picture or a flow chart that includes elements such as arrows.	Khine 2013 Guo et al. 2018 AbdelWahab 2013 Cheng et al. 2014 Khine et al. 2016

		Evagorou et al. 2015 Carney and Levin 2002 Berkeley et al. 2015
Case Studies and Examples	A case study is a real event or scenario that is presented and extensively explained while an example is a less in depth case that illustrates the concept.	Khine 2013 Choi et al. 2010 Seshan et al. 2021 UNSW 2020 SERC 2021
Prompting Questions	Questions asked relating to the general concept or direct misconception.	Nussbaum et al. 2018 Zajkov et al. 2016 Berkeley et al. 2015

4.2 – Part 2: Textbook Analysis

4.2.1 Overall Statements

Out of the six misconceptions studied, Misconception 5, outlier weather events being indicative of climate change, and misconception 6, water vapour is not a greenhouse gas were the least represented in the textbooks analyzed. Misconceptions 2, the hole in the ozone being responsible for climate change, 3, general pollution causes climate change, and 4, the greenhouse effect is not a natural phenomenon, provided the most in depth explanations within the textbooks and, therefore, the most data (Figures 4.4, 4.8, and 4.11). A summary of these results is represented in concept maps found in Figures 4.4, 4.8, and 4.11.

Some key textbooks elements for communicating concepts and misconceptions through textbooks were consistently included across the different texts with others occurring less frequently. The misconceptions were only directly refuted by the textbooks 6.25% of the time while case studies and examples were used 37.5% of the time (Figure 4.1). The more represented textbook elements were the content surrounding the misconceptions as this was included 85.4% of the time as well as figures and diagrams which were used 70.1% of the time (Figure 4.1). The inclusion of prompting questions fell in the middle being used 47.9% of the time.

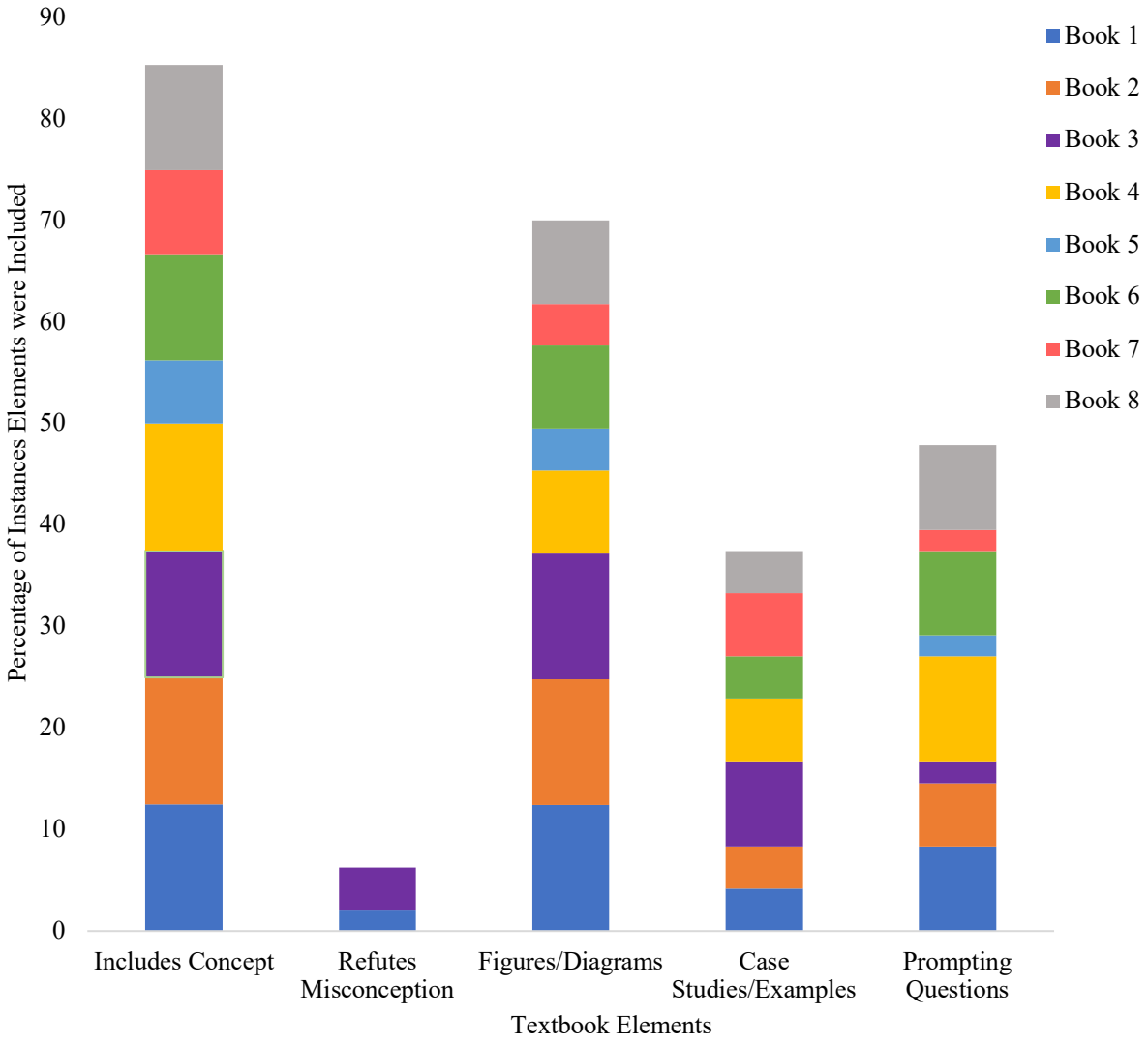


Figure 4.1. The percentage of times textbook elements were used at least once in a textbook out of 48 possible instances in regards to the misconceptions along with a breakdown of which books the elements were used in.

4.2.2 – Misconception 1: Weather versus Climate

In regards to the misconception that there is no difference between weather and climate, many similarities were observed across all books. All textbooks, except for textbook seven (Fisher 2019), included the concepts related to this misconception and showed similarities in the ways they defined weather and climate. The following terms were used across the textbooks when defining weather: short term, local geographic areas, and given time and place. The influences and causes of weather such as temperature, humidity, air pressure, and Hadley cells were also included in textbooks one (Withgott et al. 2013), two (Withgott et al. 2017), three

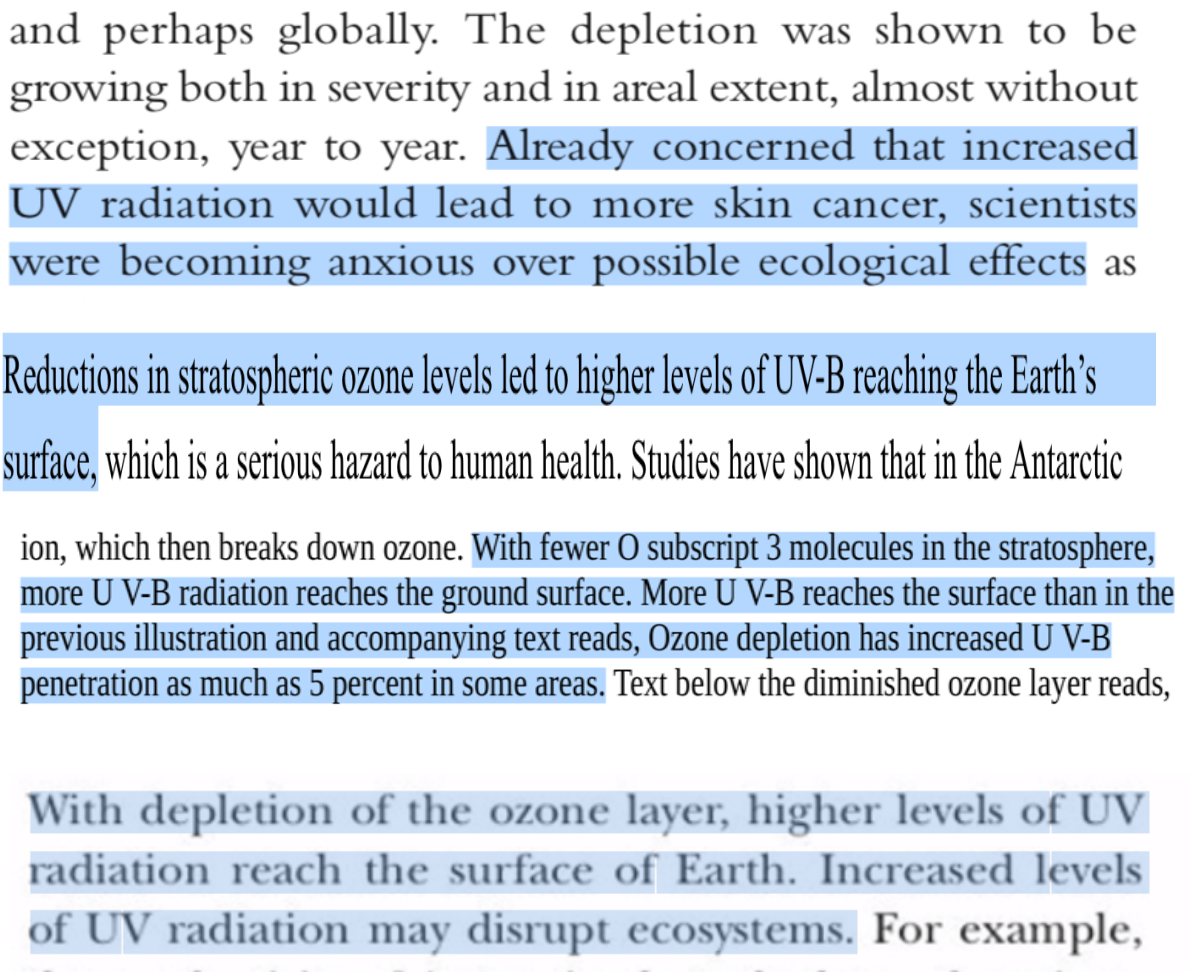
(Withgott and Laposata 2021), and eight (Berg et al. 2010). The following terms were used across all textbooks to define climate: long term, patterns and trends, and regional geographic scales. Book eight (Berg et al. 2010) expanded on this definition by also including the causes of climate such as variations with latitude, elevation, and topography.

The four remaining textbook elements, misconception refutation, figure and diagram use, case study and example use, and inclusion of questions were rarely included across all textbooks for Misconception 1. The misconception was not directly refuted by any of the textbooks. Diagrams and figures were used in textbooks one (Withgott et al. 2013), two (Withgott et al. 2017), three (Withgott and Laposata 2021), and eight (Berg et al. 2010). Each of these textbooks featured flow diagrams showing how different types of weather are influenced by jet streams and Hadley cells and how climate is influenced by solar energy. Examples were used in textbooks three (Withgott and Laposata 2021), four (Karr et al. 2021), six (Molles and Borrell 2016), and eight (Berg et al. 2010) and a single case study in textbook eight (Berg et al. 2010) explored a climatology career further expanding on the differences between weather and climate. Each example provided a specific location along with a description of its climate versus the weather. Finally, there were questions used by textbooks two (Withgott et al. 2013), four (Karr et al. 2021), five (Dearden et al. 2020), six (Molles and Borrell 2016), and eight (Berg et al. 2010) with each question asking the reader to distinguish between weather and climate. Book two (Withgott et al. 2013) had one additional question asking how solar energy influences weather versus how it influences climate.

4.2.3 – Misconception 2: The Ozone Layer's Role in Climate Change

Content explaining the concepts associated with Misconception 2, the ozone layer is primarily responsible for climate change and global warming, was included in all textbooks except textbook six (Molles and Borrell 2016). There were two main concepts described in every textbook: defining the ozone layer and ozone layer depletion (Figure 4.2). When defining the ozone layer, the terms stratosphere, UV filter and shield, and composed of O_3 molecules were common across all books. When defining ozone layer depletion, all textbook stated that the ozone hole refers to areas of thinner ozone concentration. The process of ozone depleting substances (ODSs) breaking down the ozone layer with a specific focus on the role of chlorofluorocarbons (CFCs) was a common theme. Additionally, all textbooks except for

textbook five stated that the ozone hole would allow for excess UV radiation to enter the atmosphere (Figure 4.4).


and perhaps globally. The depletion was shown to be growing both in severity and in areal extent, almost without exception, year to year. Already concerned that increased UV radiation would lead to more skin cancer, scientists were becoming anxious over possible ecological effects as

Reductions in stratospheric ozone levels led to higher levels of UV-B reaching the Earth's surface, which is a serious hazard to human health. Studies have shown that in the Antarctic

ion, which then breaks down ozone. With fewer O subscript 3 molecules in the stratosphere, more U V-B radiation reaches the ground surface. More U V-B reaches the surface than in the previous illustration and accompanying text reads, Ozone depletion has increased U V-B penetration as much as 5 percent in some areas. Text below the diminished ozone layer reads,

With depletion of the ozone layer, higher levels of UV radiation reach the surface of Earth. Increased levels of UV radiation may disrupt ecosystems. For example,

Figure 4.2. An example taken from textbook two (Withgott et al. 2013), four (Karr et al. 2021), seven (Fisher 2019), and eight (Berg et al. 2010) showing a statement that was common amongst the textbooks regarding the ozone depletion causing increased UV radiation.

The misconception was only directly refuted in textbook three (Withgott and Laposata 2021), the most recent edition, as it stated, "a common misconception held by many people is that the ozone hole is related to global warming" (Withgott and Laposata 2021). The correct concept was then explained stating that global warming and ozone depletion are two separate issues as one allows for excess UV radiation in the atmosphere while the other warms or cools the atmosphere. It was also stated that there is much overlap between ODSs and GHGs which may be the root of the misconception (Withgott and Laposata 2021):

"Is the ozone hole related to global warming? A common misconception held by many people is that the ozone hole is related to global warming. In reality, stratospheric ozone depletion and global warming are completely different issues. Ozone depletion allows excess ultraviolet radiation from the sun to penetrate the atmosphere. Conversely, global warming does not appreciably affect ozone loss. However, by coincidence many ozone-depleting substances banned by the Montreal Protocol also happened to be greenhouse gases that warm the atmosphere. Thus, although the Montreal Protocol was designed to combat ozone depletion, it has also helped us slow climate change. In a further unexpected link, when CFCs were phased out, industry replaced them with chemicals called HFCs which are harmless to ozone- but which happen to be powerful greenhouse gases…"

-Withgott and Laposata 2021

Each textbook, except for textbook six (Molles and Borrell 2016), exhibited similarities in which figures and diagrams were included (Figure 4.3). A flow diagram depicting the process of CFCs breaking down O_3 molecules as well as graphs of the hole in the ozone layer over time were included across all textbooks. Diagrams of the atmospheric layers and line graphs displaying the fluctuations in ozone levels over time were included in multiple textbooks, but were less common.

Textbooks one (Withgott et al. 2013), two (Withgott et al. 2017), and three (Withgott and Laposata 2021) each included the same case study which outlined a team of Nobel Prize winners from 1995 and their research on the causes of ozone depletion (Figure 4.3). Prompting questions were included in all textbooks except for textbook five (Dearden et al. 2020) and textbook six (Molles and Borrell 2016). A common theme among the prompting questions was to ask about the causes and impacts of ozone depletion including asking about the roles of CFCs and ODSs in the process (Figure 4.3). Only textbook three (Withgott and Laposata 2021) asked a question directly related to the misconception saying, "is the ozone hole related to global warming?" (Withgott and Laposata 2021).

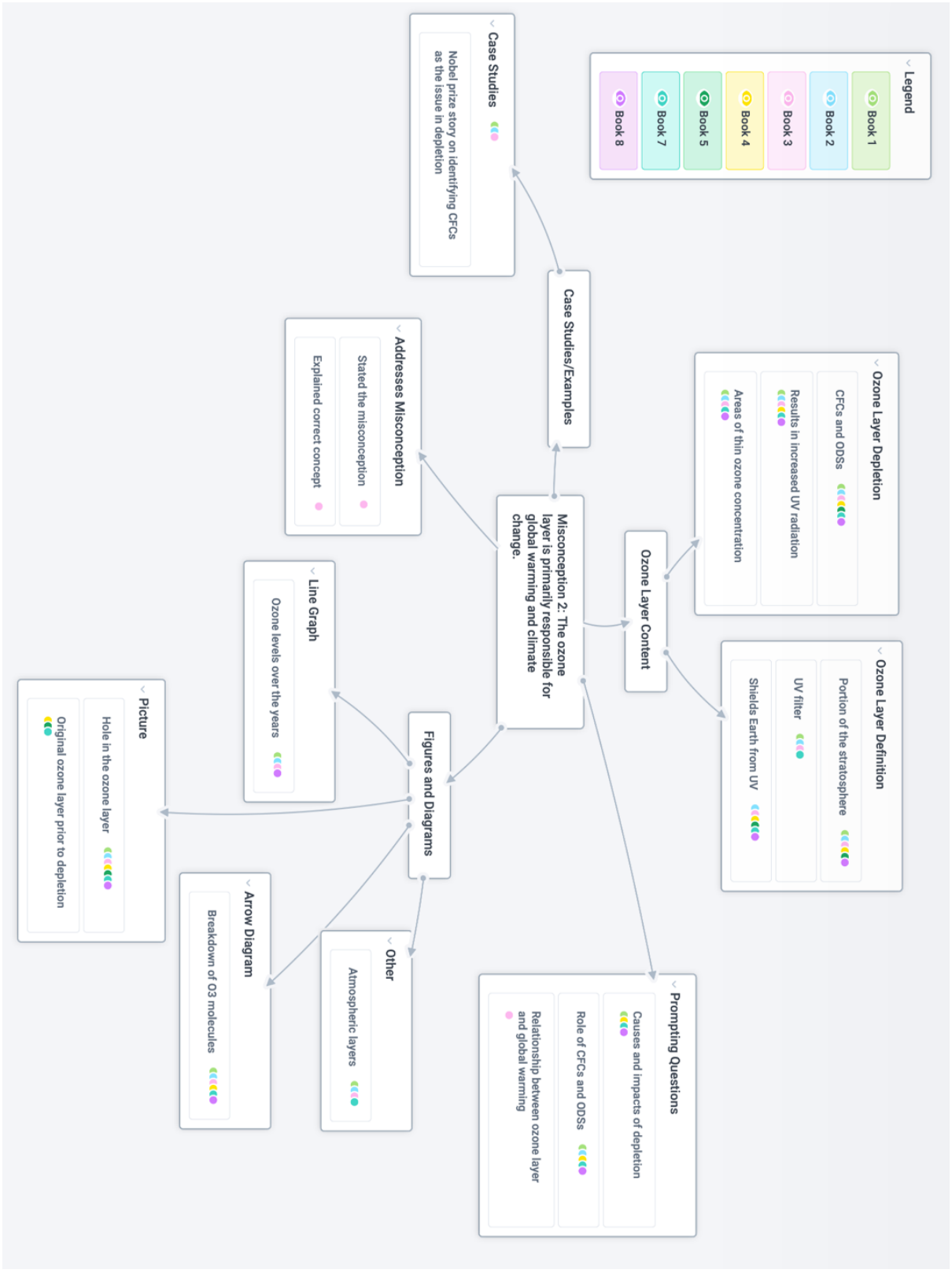


Figure 4.3. A concept map illustrating a breakdown of the common themes observed within the five textbook elements for Misconception 2.

4.2.4 – Misconception 3: Which Pollution Types Can Cause Climate Change

All textbooks, with the exception of textbook five (Dearden et al. 2020), included extensive content regarding the third misconception of general pollution causing climate change (Figure 4.7). Large lists of both natural and anthropogenic pollutants with their associated causes and environmental impacts were also included in all textbooks except for textbook four (Karr et al. 2021) and five (Dearden et al. 2020). All textbooks, again with the exception of textbook five (Dearden et al. 2020), explored the differences between point and non-point sources of pollution as well as primary and secondary pollutants. Furthermore, each of the textbooks focussed heavily on air pollution defining it as harmful substances that are released into and are present in the atmosphere (Figure 4.7). Textbooks one (Withgott et al. 2013), two (Withgott et al. 2017), three (Withgott and Laposata 2021), four (Karr et al. 2021), and eight (Berg et al. 2010) directly state that air pollution affects the climate and plays a role in climate change (Figure 4.4 and 4.5). Additionally, there was a strong focus on aerosols throughout many of the books where the impacts they can have on the climate, the sources of them, and their interaction with solar rays were explained (Figure 4.6).

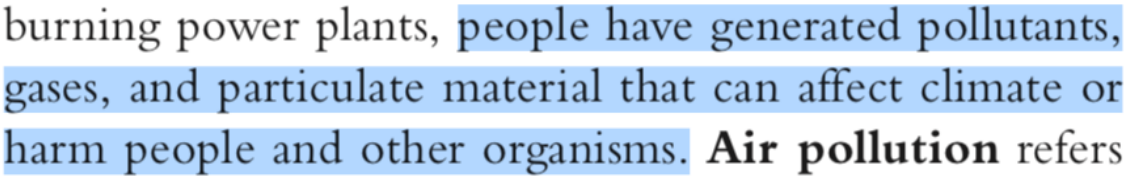

burning power plants, people have generated pollutants, gases, and particulate material that can affect climate or harm people and other organisms. **Air pollution** refers

Figure 4.4. A statement from textbook two (Withgott et al. 2013) displaying the common theme of stating pollution can influence climatic changes.

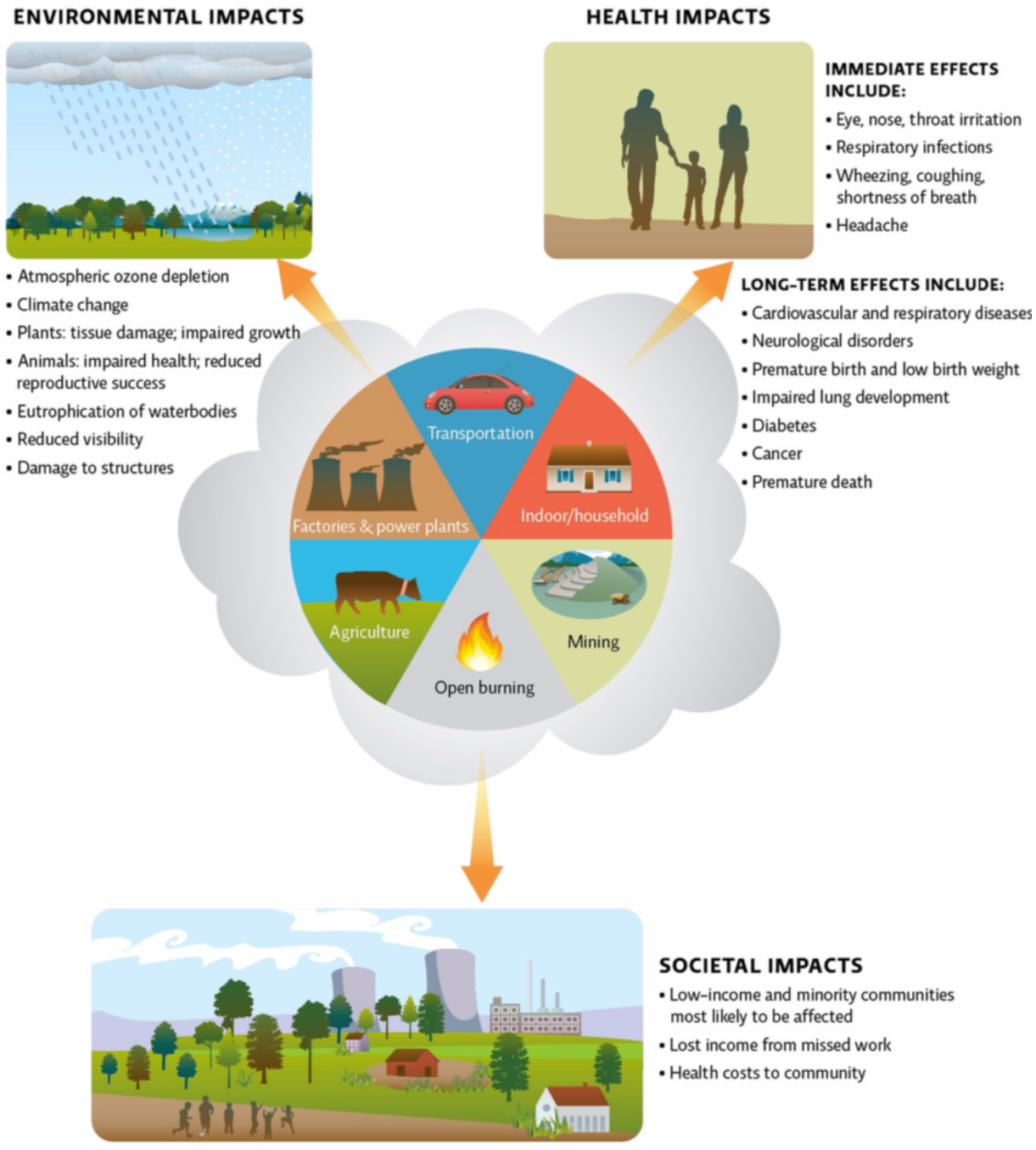


Figure 4.5. An example of a diagram in textbook four (Karr et al. 2021) stating that such pollution emitting actions can have an impact on climate change.

The misconception was never directly refuted by any of the textbooks. However, there were 16 figures and diagrams used across all books with many similarities being displayed (Figure 4.7). Five of the textbooks included pictures of volcanoes erupting to show the release of aerosols (Figure 4.6). Furthermore, three of the textbooks included flow diagrams displaying the

sources of various natural and anthropogenic pollutants, their final destinations, and their impacts throughout their lifespan. However, many of the textbooks failed to directly distinguish between which actions and pollutants were climate forcers capable of influencing climate change (Figure 4.5). Textbooks, one (Withgott et al. 2013), three (Withgott and Laposata 2021), six (Molles and Borrel 2016), and eight (Berg et al. 2010) used the same case study from 1991 of a major volcanic eruption of Mount Pinatubo in the Philippines responsible for temporarily cooling the global climate. Other common case studies regarded natural pollutants, such as dust storms, and the impact their pollution can have (Figure 4.6). Questions related to this misconception mainly concerned defining air pollution as well as listing the environmental impacts of the various types of pollutants (Figure 4.7).

Figure 4.6. An example of a case study from textbook eight that was common across many textbooks highlighting the impact on climate a 1991 volcanic eruption had (Berg et al. 2010).

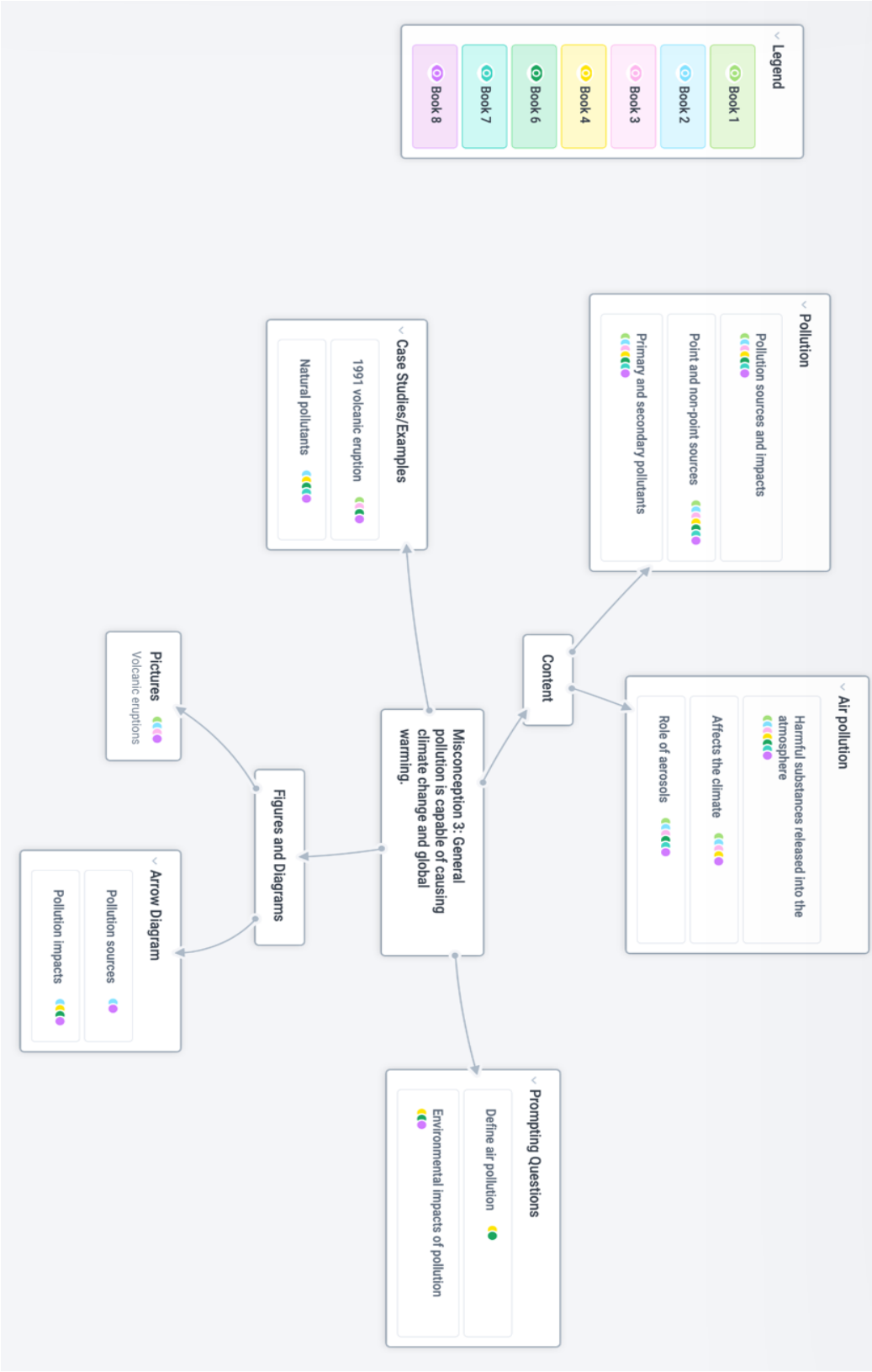


Figure 4.7. A concept map exploring the common themes related to Misconception 3 observed among the five textbook elements and all textbooks.

4.2.5 – Misconception 4: The Process and Role of the Greenhouse Effect

All eight textbooks included similar content related to Misconception 4 which concerns the greenhouse effect being entirely human caused rather than enhanced by human actions (Figure 4.10). Each textbook uses the term 'naturally varies' when introducing climate change with five books using the term 'natural phenomenon' when introducing the greenhouse effect. All textbooks, with the exception of textbook six (Dearden et al. 2020), state that human activities are enhancing the greenhouse effect which is in turn changing the climate. Furthermore, all eight textbooks discuss the natural influences on the greenhouse effect and climate change by describing processes like albedo, radiative forcing, and Earth's axil tilt.

Textbook three (Withgott and Laposata 2021), the most recent edition used within the study, was the only textbook to refute the misconception (Figure 4.10). To do this, there was a separate section included where it was stated that while, "our planet's climate varies naturally, today's disruptive changes are unfolding at an exceedingly rapid rate, and they are creating conditions humanity has never experienced" (Withgott et al. 2021) . There were a significant amount of figures and diagrams used in all eight textbooks in relation to this misconception (Figure 4.9). Every textbook except for textbook seven (Fisher 2019) included a flow diagram of the natural greenhouse effect without any anthropogenic factors acting on it (Figure 4.8). Other common diagrams depicted natural versus anthropogenic fluxes of carbon dioxide, the Milankovitch's cycle's natural impact on the greenhouse effect, and a line graph of carbon dioxide concentrations over hundreds to hundreds of thousands of years (Figure 4.9).

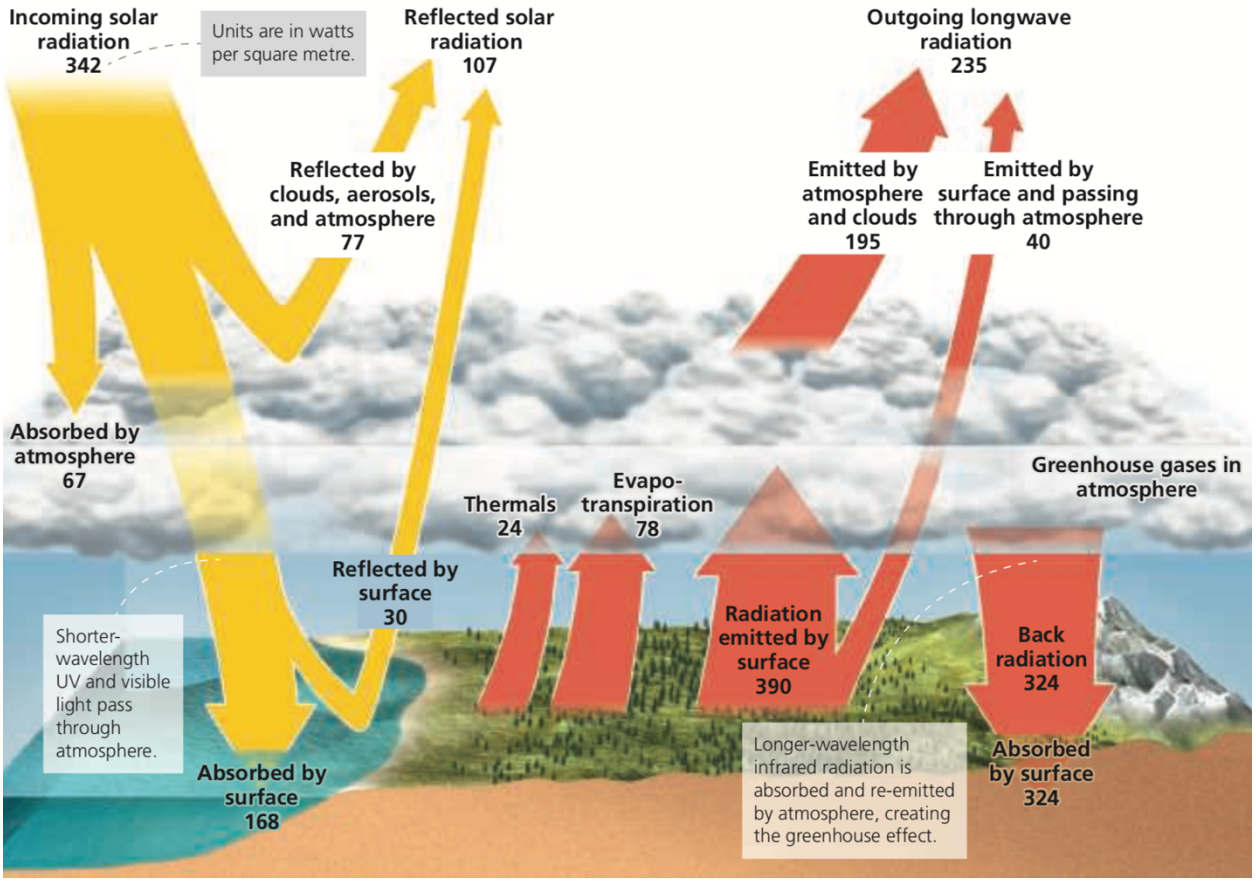


Figure 4.8. An example from textbook two (Withgott et al. 2017) of a flow diagram used across all but one book that depicts the natural greenhouse effect without any anthropogenic factors influencing it.

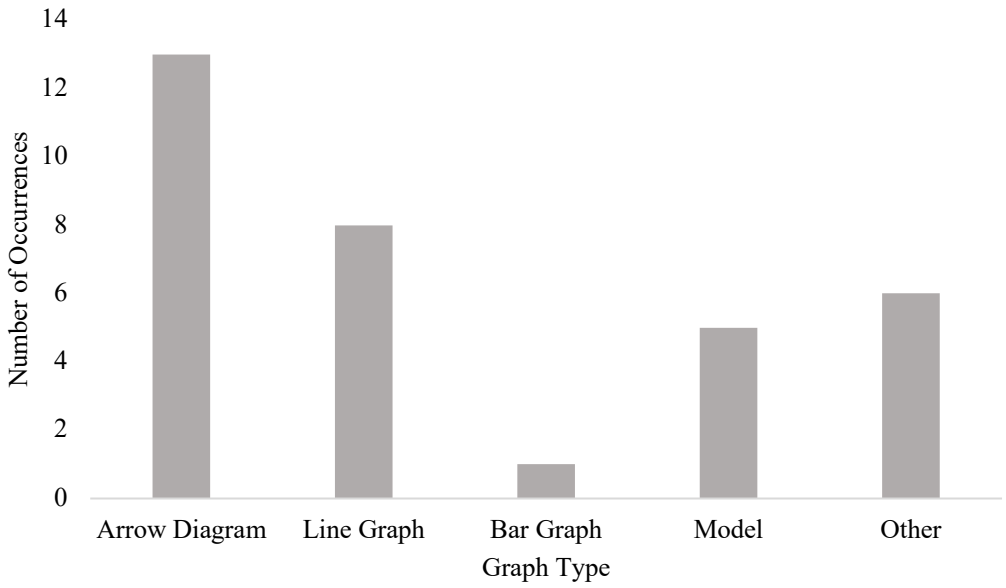


Figure 4.9. The number of each type of graph used across all textbooks when presenting concepts related to Misconception 4.

Only textbook seven (Fisher 2019) included an example in which the process of the natural greenhouse effect was compared to a gardening greenhouse and a car on a hot day (Figure 4.10). Finally, there were prompting questions used in half of the textbooks including books one (Withgott et al. 2013), four (Karr et al. 2021), six (Dearden et al. 2020), and eight (Berg et al. 2010) (Figure 4.10). A common theme among these questions regarded the natural versus anthropogenic factors influencing climate change and the greenhouse effect as this question was asked in three out of the four books. One example of this can be seen in textbook six where it is asked, “What are the key natural and human causes of climate change?” (Dearden et al. 2020).

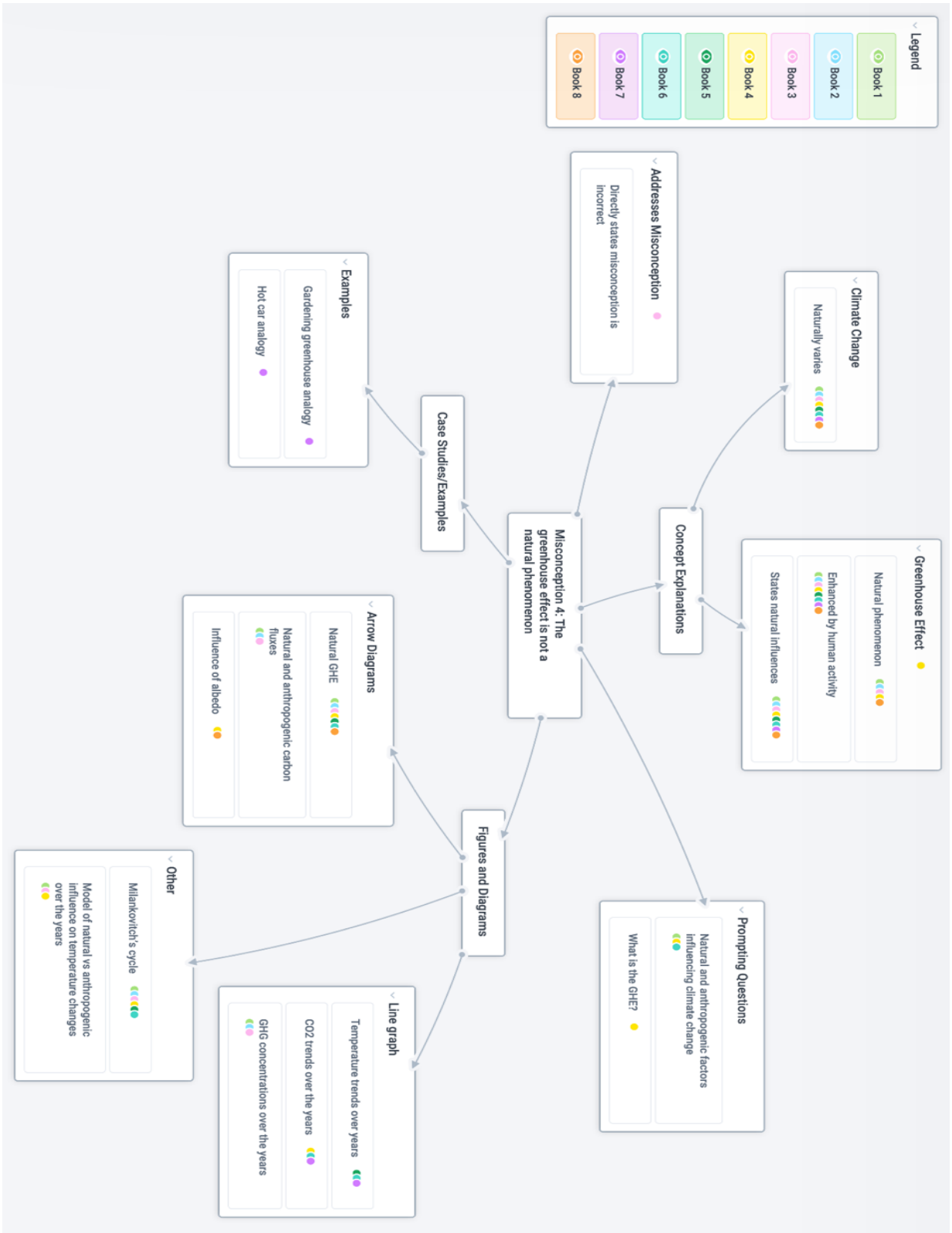


Figure 4.10. A concept map displaying an analysis of the common themes related to Misconception 4 observed within the five textbook elements.

4.2.6 – Misconception 5: Outlier Weather Events Indication of Climate Change

Content surrounding Misconception 5, outlier weather days being indicative of climate change, was included within five textbooks with book five (Molles and Borrell 2016), seven (Fisher 2019), and eight (Berg et al. 2010) having no mention of it. Textbooks two (Withgott et al. 2017), three (Withgott and Laposata 2021), and four (Karr et al. 2021) had the most content with all specifically stating that a single weather event cannot be attributed to climate change and that long term temperature patterns must be observed before concluding that the climate has changed.

Textbook one (Withgott et al. 2013), directly refuted the misconception through a case study stating that there is typically public discourse regarding climate change and whether an unusual weather day can indicate long term climate change (Withgott et al. 2013). Line and bar graphs displaying the annual mean temperatures over time were the common figures used in textbooks one (Withgott et al. 2013), two (Withgott et al. 2017), Three (Withgott et al. 2021), and six (Dearden et al. 2020). Textbook four (Karr et al. 2021), included a bar and line graph displaying the pattern of extreme weather events over 110 years.

The only textbooks to use case studies and examples were one (Withgott et al. 2013), three (Withgott and Laposata 2021), and four (Karr et al. 2021). Both case studies examined the link between global warming and extreme weather events with one featuring a climatologist's perspective. Textbook four included specific weather events such as hurricane Katrina and Irma as examples while textbook three used the analogy, "When a baseball player takes artificial steroids and starts hitting more home runs, you can't attribute any one particular home run to the steroids, but you can conclude that steroids were responsible for the increase in home runs" (Withgott and Laposata 2021). Only textbooks four (Karr et al. 2021) and six (Dearden et al. 2020), included questions pertaining to the connection between climate change and extreme winter storms.

4.2.7 – Misconception 6: Water Vapour as a Greenhouse Gas

All textbooks, with the exception of textbook five (Molles and Borrell 2016), included content relating to Misconception 6, that water vapour is not a greenhouse gas. Each of these textbooks lists water vapour as a greenhouse gas with five of them stating it is the most abundant and contributes the most to the natural greenhouse effect. Another common theme observed throughout many of the books was the role water vapour plays in positive and negative feedback

loops and how these loops influence atmospheric temperatures. Additionally, five of the textbooks, one (Withgott et al. 2013), two (Withgott et al. 2017), four (Karr et al. 2021), six (Dearden et al. 2020), and eight (Berg et al. 2010), describe water vapour as a greenhouse gas and thus its relationship with infrared radiation in terms of how it absorbs and redirects it.

This misconception was not refuted by any of the textbooks and did not include any case studies or examples. In terms of figures and diagrams used, a pie chart displaying the different amounts of greenhouse gases in the atmosphere was included in textbooks one (Withgott et al. 2013), two (Withgott et al. 2017), three (Withgott and Laposata 2021), and six (Dearden et al. 2020). Textbook six (Dearden et al. 2020) had an additional flow diagram displaying water vapour feedback loops and line graph showing the correlation between surface temperatures and water vapour levels. Only two of the textbooks, one (Withgott et al. 2013) and two (Withgott et al. 2017), used questions related to this misconception with both of them pertaining to the large role of water vapour in some feedback loops.

Chapter 5: Discussion

5.1 – Overall Statements

The results from this study suggest that widely used introductory environmental science textbooks have room to improve their approaches to commonly held climate change misconceptions. The amount of content associated with the misconceptions varied across each misconception with a seeming connection between the more the misconception was cited in the literature, the more content was presented. For example, misconception two of ozone depletion playing a primary role in climate change was stated the most in the literature and had an abundance of data associated with it across the textbooks.

The opposite was true for the textbook elements as the most cited from the literature element was represented the least within the textbooks. Refutation texts, stating a misconception and explaining the correct scientific concepts behind it, was overwhelmingly found to be the most effective textbook element in combatting misconceptions according to the literature review (Dole 2011; Ferrero et al. 2020; Tippett 2010). This is likely due to its ability to induce cognitive conflict by revealing the inaccuracy of the reader's preconceived notions resulting in conceptual change (Tippett 2010). Despite this, the results of the present study show it was the least included element by far across all textbooks, as only two texts included it, which is consistent with the findings of Tippett's literature review and secondary analysis study that determined refutation texts were severely lacking in scientific texts (2009) (Figure 4.1). This presents a problem as many misconceptions are deeply rooted and resistant to change requiring more than expository texts or an explanation of scientific concepts to promote a shift in mental models (Tippett 2010; Dole 2011). However, it was the most recently published textbooks from 2020 and 2021 that included refutation texts indicating that authors may be increasingly aware of the effectiveness of this element and are attempting to include it in their texts.

Another underrepresented textbook element was the use of case studies and examples. Case studies and/or examples can assist students in connecting the material to reality and provide additional context to aid with enhanced comprehension (Khine 2013; SERC 2021). As such, the failure to prioritize the inclusion of case studies and/or examples can potentially act as a barrier to student learning resulting in their misconceptions remaining unchallenged. Alternatively, the high inclusion rates of the content related to the misconceptions and figures and diagrams suggests that these elements are a common practice across environmental science textbooks

which can help in student learning in many instances (Berkeley et al. 2015; Khine 2013; Choi et al. 2010; Evagorou et al. 2015).

5.2 – Misconceptions

5.2.1 – Misconception 1: Weather versus Climate

Misconception 1, the misconception of weather versus climate, was one of the more well documented misconceptions in the literature as it was mentioned by six studies (Choi et al. 2010; Lombardi and Sinatra 2012; Nussbaum et al. 2018; Rebich and Gautier 2005; Fleming et al. 2021; Gautier et al. 2018). All of the textbooks, with the exception of one, explained the concepts related to weather versus climate in a similar manner where climate and weather were both individually clearly defined. This finding is consistent with that of Choi et al.'s (2010) study as they noted many textbooks defined these terms separately. The remaining four textbook elements including refutation text, the inclusion of figures and diagrams, case studies and/or examples, and practice questions were underrepresented in the texts leaving room for improvement in how textbooks are teaching about this particular misconception.

However, there was one open-ended question across many of the textbooks that asked for the difference between weather and climate. While this does not state that there is a misconception surrounding this, it does challenge students to consider an answer as well as the science behind this answer. This question could work to combat misconception one as challenging one's prior knowledge is one method of inducing conceptual change (Tippett 2010).

5.2.2 – Misconception 2: The Ozone Layer's Role in Climate Change

Misconception 2, the ozone layer's primary role in climate change, was the most prevalent misconception within the literature with nine studies acknowledging it (Table 4.1).The role of the stratospheric ozone layer is considered a key concept in environmental science as it was extensively explained across all textbooks with numerous examples of the key textbook elements being applied. This suggests that the collected content segments should be analyzed for any factors proven to cause misconceptions such as incorrect information, generalizations, or oversimplifications.

An example of this was found in the majority of textbooks as they stated that ozone depletion results in increased UV radiation reaching the surface causing environmental and ecological impacts (Figure 4.2). In many instances, this statement was not further expanded on leaving room for the reader to interpret what these environmental impacts are. The vague nature

of this content is problematic as incomplete and vague statements are one way misconceptions can arise (Soeharto et al. 2019). Conceptual misunderstandings, a type of misconception, stem from scientific content that is not fully understood leading students to produce their own faulty models to deal with the confusion (Soeharto et al. 2019; National Academy Press 1997). This lack of further explanation could be contributing to the proliferation of this misconception.

Another factor that could contribute to the perpetuation of this misconception is the location of the content regarding the ozone layer. In some of the textbooks, the ozone layer was described in the climate change chapters rather than the atmospheric science chapters. This placement can cause students to incorrectly associate climate change with the ozone layer or ozone depletion leading to misconceptions (Choi et al. 2010).

Alternatively, there were many positives associated with this misconception within the textbooks as many elements were used. One textbook included a perfect example of a refutation text which, as previously mentioned, has been deemed most effective in combatting misconceptions (Tippett 2010; Nussbaum et al. 2018; Ariasi and Mason 2011). This textbook also went on to specifically ask if the ozone hole was related to global warming further prompting students to question their own mental models and ensure that they are correct. These methods gives students the best possible chance of correcting this misconception. Furthermore, the flow diagrams for this misconception included more extensive chemistry than any other misconception which can also contribute to combatting this misconception as oversimplifications can work to proliferate them (King 2010).

5.2.3 – Misconception 3: Which Pollution Types Can Cause Climate Change

The findings for Misconception 3 were similar to those of Misconception 2 as there was an abundance of content associated with pollution included across the textbooks, yet this was also the most prominent misconception based on the literature. This suggests that the content segments collected should be further analyzed to determine any areas of possible proliferation there.

Throughout many of the textbooks, lists of common pollutants, with their associated sources and impacts, were given (Figure 4.7). However, there was rarely any distinction made between air pollutants and climate forcers with most textbooks using air pollutants as an umbrella term. This distinction is especially critical as many of the textbooks stated air pollutants play a role in changing the climate and, without specifying, this can generate confusion as to

which pollutants are having the impact (Choi et al. 2010; Varela et al. 2018). Furthermore, some diagrams were misleading as sources and impacts were lumped together making it difficult for readers to connect the specific pollutant with its impact and differentiate between those pollutants that can act as climate forcers and those that can cause human health issues (Figure 4.6). Similar to Choi et al.'s (2010) findings, the failure of the textbooks to specifically state the relationships between certain pollutants, climate change, and the greenhouse effect can risk further perpetuating this misconception.

The generalized manner in which this content is presented as well as the common theme of the 1991 Mount Pinatubo volcanic eruption case study included in many of the textbooks can work to create another issue. Not pointing out specific human actions and using a natural example of air pollution, such as volcanic eruptions, as the sole case study related to this content can also create a disconnect between readers' actions and the impacts they're having on the environment (Wyner and DeSalle 2020). If readers are unable to connect their personal, everyday actions to the material, they are less likely to acknowledge and potentially change their impact on the environment (Wyner and DeSalle 2020). This inability to connect with the material could also hinder one's full understanding of which pollutants cause which impacts. Alternatively, textbook eight (Berg et al. 2010) included a case study highlighting the impacts anthropogenic pollution has on the environment versus the impacts of natural pollutants. The inclusion of more relatable examples could lead to reader recognizing the pollution consequences of their own actions.

5.2.4 – Misconception 4: The Process and Role of the Greenhouse Effect

The content associated with Misconception 4, the greenhouse effect is human caused, was extensively covered throughout all textbooks with all books either using the term 'naturally varies' or 'natural phenomenon' to describe climate change and the greenhouse effect. The use of these terms directly states that this is the correct concept, but does not provide an explanation as to why alternative concepts, such as misconception four, are incorrect. This lack of refutation will likely be insufficient in achieving conceptual change due to the resilience of most misconceptions (Tippett 2010; King 2010). Therefore, more information is required to combat this misconception through textbooks. However, one textbook did specifically refute this misconception explaining the misconception and the science behind the corrected concept.

Case studies and examples were severely lacking in regards to this misconception with only one being used across all textbooks to compare the greenhouse effect to a physical greenhouse. However, this metaphor has been found to be detrimental to students enrolled in education past a middle school level as it oversimplifies the concept or presents it incorrectly all together leading to faulty thinking (Choi et al. 2010; Chen 2012; Gautier et al. 2018). The metaphor promotes incorrect understandings about the greenhouse effect and climate change such as the belief that CO_2 has immediate effects on the climate system (Chen 2012). It also encourages the idea that warm air is trapped inside a barrier (Gautier et al. 2018). Furthermore, it was found to be less effective when students are memorizing text rather than actively learning concepts, which is the method commonly used by students (Oh and Jeon 2017). Ultimately, the single example used for misconception four is flawed suggesting the need for improvements in this area.

One positive inclusion of the elements for this misconception was the widely used diagram of the natural greenhouse effect omitting anthropogenic factors. This shows that there are natural drivers of the greenhouse effect without human presence acting on it.

5.2.5 – Misconception 5: Outlier Weather Events Indication of Climate Change

There were limited data available for Misconception 5, outlier weather events indicating climate change, across most textbooks. The most notable theme across many of the textbooks was the outright statement that single weather events cannot be attributed to climate change. While this is a positive statement that could contribute to combatting the misconception, it could be made more effective against resilient misconceptions as refutation texts are proven to be more beneficial than expository (Tippett 2010). One textbook did refute this misconception through the use of a case study which may prove to be additionally effective as it combines two of the key textbook elements.

5.2.6 – Misconception 6: Water Vapour as a Greenhouse Gas

Misconception 6, water vapour is not a greenhouse gas, also lacked content surrounding it throughout the textbooks. A few of the textbooks provided an in-depth explanation and used figures/diagrams of the positive and negative feedback loops associated with water vapour that have the ability to influence climate. However, these textbooks also stated that confusion surrounding water vapour's exact role in these feedback loops remains. The lack of certainty

regarding this subject may be contributing to the discourse and incorrect understanding of water vapour as a role as a greenhouse gas.

Chapter 6: Conclusion

6.1 Summary

The impacts of climate change are becoming more prevalent in societies today highlighting the need for environmental education with a concentration on climate literacy. Common misconceptions regarding climate change can act as a barrier to climate literacy indicating the need to address them. This study examined university level textbooks currently used in introductory environmental science courses in Canada to determine the extent to which key textbook elements were used to approach common climate change misconceptions.

This study shows that there is much room for improvement in terms of the key elements being included to present content associated with climate change misconceptions. Refutation texts are largely underrepresented across all textbooks despite the literature citing it as the most effective method in inducing conceptual change. The use of case studies and/or examples is also excluded in many instances. Broad generalizations lacking specific wording and diagrams are made across many of the textbooks, particularly where Misconception 3 and 4 are concerned. Furthermore, little content is present for some of the misconceptions while others have large amounts.

The results of this study contribute to the existing body of knowledge on climate change misconceptions in classrooms and textbooks. This study aimed to fill literature gaps and present unique findings as it focussed on university level textbooks currently in use within Canada. The study also allows for updated research in regards to the Choi et al. (2010) study as similar methods were used, but the textbooks analyzed were published in 2002-2006. This is critical as it provides insight on the steps textbooks have taken in regards to misconceptions since the 2010 study was conducted 13 years ago.

To continue to fill literature gaps and inform educators on correcting misconceptions, future studies should conduct a short term and long term pre-test and post-test to measure the ability of each of the textbook elements to correct resilient misconceptions. Another study should compare the ability to correct climate change misconceptions when textbooks are used as the sole resource versus when textbooks are used with hands-on, experimental activities as textbooks are only one component of teaching.

6.2 Recommendations

This study provides insight on the inclusion of key textbook elements to present common climate change misconceptions. The results allow for future recommendations to be made in this area of study.

As previously stated throughout this study, climate change misconceptions can hinder an individual's ability to be climate literate. As such, it is vital that authors of educational resources, especially textbooks, are aware of these misconceptions. The authors' knowledge of these misconceptions can then allow them to intentionally address them within the text which will ultimately increase the chances of diminishing them. Furthermore, the authors are then able to use the textbook elements capable of aiding comprehension of text to present and address these common misconceptions.

In terms of recommendations for the key textbook elements, refutation texts, case studies and examples, and prompting questions need to be included more throughout textbooks especially where misconceptions are concerned. There is much evidence to suggest that refutation texts promote conceptual change resulting in the correction of misconceptions, even when they are considered to be resilient. If authors are aware of common misconceptions, they can integrate this element to assist in combatting them. Additional case studies and examples can also be included in regards to misconceptions to assist students in establishing a connection to reality and address their misconceptions. Prompting questions can encourage students to consider the science behind their mental models perhaps making them question it. This can lead to the questioning of their own incorrect beliefs possibly altering or correcting them in the process. Alternatively, the content associated with the misconceptions and figures and diagrams were two textbook elements that were sufficiently included across the analyzed textbooks. As such, it is important that these elements continue to be included at the same, if not higher, rate to continue assisting in comprehension.

While textbooks are one of the main relied upon resources in educational settings, they are only one piece to a greater puzzle. Hands-on activities, repeated corrective language, and teacher instruction are all other methods of correcting misconceptions that also need to be integrated into a classroom setting. This is reinforced through the idea of constructivist theory of instruction where textbooks cannot be the sole resource for learning (Mill et al. 2006). The

combination of various teaching techniques will increase the chances of diminishing misconceptions rather than relying on a sole resource.

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Appendix

Table A. The reference, study type, and study subject/sample that each of the misconceptions seen in Table 4.1 were derived from.

Reference	Study Type	Study Subject/Sample
Choi et al. 2010	Literature review	Middle and high school students
Lombardi and Sinatra 2012	Literature review	Undergraduate students
Nussbaum et al. 2018	Literature review	Undergraduate students
Boon 2010	Literature review	High school students and pre-service teachers
McCaffrey and Buhr 2008	Literature review	American students, teachers, and public
Shepardson et al. 2010	Literature review and empirical (survey)	High school students
Román and Busch 2015	Empirical (Analysis)	Middle school students and texts
Varela et al. 2018	Empirical (Test)	Middle school students
Rebich and Gautier 2005	Empirical (Survey)	Undergraduate students
Chang and Pascua 2015	Empirical (Interview)	High school students
McCuin et al. 2018	Empirical (Pre and post-test)	Undergraduate students
Fleming et al. 2021	Empirical (Interview)	General public in the US
Gautier et al. 2018	Empirical (Survey)	Undergraduate students
Fortner 2001	Empirical (Survey)	High school and undergraduate students and teachers
Papadimitriou 2004	Empirical (Survey)	Student teachers