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# Exploring Adolescents' Critical Reading of Socioscientific Topics Using Multimodal Texts

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**Abstract**
This qualitative within-individual case design study involved six adolescents (age 10–14 years) engaging in a think-aloud observational protocol to read two texts on climate change from contrasting viewpoints. The participants completed a prior knowledge assessment and survey of technology used to assess potential mediating factors. Survey and observational data are presented as participant profiles. Results illustrated the effect of participants' background knowledge, emotional elicitation of text features, cognitive dissonance argument analysis due to the contrasting multimodal texts, and impact of visual images on participants' comprehension. Our data analyses revealed that there is an interconnected and nuanced relationship amongst many text and individual factors when adolescents engage in critical reading of SSI multimodal texts. This research provides direction for future science education research that support learners in critical reading of complex socioscientific topics as presented in multimodal texts with adolescent learners.

**Keywords** Science education · Multimodal texts · Critical reading · Adolescent learners · Case study design · Climate change

## Introduction

Democracy is strengthened when citizens are equipped to effectually respond to societal issues such as climate change or the COVID-19 pandemic (Hopf et al., 2019; Sharon & Baram-Tsabari, 2020). Regrettably, the disconnect between scientific understanding and public knowledge is increasing in many jurisdictions (e.g., Chung, 2017; Funk, 2017). The need for rigorous public understanding of science is ever important when citizens frequently confront complex, conflicting information

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on challenging scientific topics in media reports and social media commentary online (Sinatra & Hofer, 2016). While some curricular efforts are in place about media literacy and science topics, these efforts have been overwhelmingly focused on language arts (language literacy) programming (e.g., MediaSmarts, 2019; Ontario Ministry of Education [OME], 2016). Teaching critical reading through science and media literacy pedagogies is not common practice with elementary or secondary science teachers (Fazio & Gallagher, 2019; Goldman et al., 2016; Yore, 2018), and particularly with complex scientific issues like climate change (Bowen, 2011).

In line with many science curriculum declarations globally, in England, the *Science Programme of Study* (Department of Education, 2015), the USA's *Next Generation Science Standards* (Achieve Inc., 2013), and Ontario, Canada's *Science & Technology, Grades 1–8* (OME, 2007), the acquisition of literacy skills is essential to support reading for meaning in science, and an important aspect of scientific literacy. The three main dimensions of scientific literacy are the core disciplinary concepts or ideas, the nature of scientific practices and processes, and the application of scientific ideas for societal impact (Hodson, 2011; Roberts & Bybee, 2014). When these dimensions intersect, scientific literacy manifests itself with students. At this juncture lies the interdisciplinary space whereby modes of communication are utilized for science and language learning (Houseal et al., 2016). Thus, we interpret "literacy" in a fundamental way in order to support students developing scientific literacy in a derived sense, as they strive to develop scientific knowledge and dispositions toward the discipline of science (Norris & Phillips, 2003).

Student learning of *socioscientific issues* (SSI) has been an emphasized topic globally in science curriculum documents and proclamations (Zeidler, 2014). There is unanimity concerning its benefit for students and science teacher practice (Feinstein et al., 2013; Peel et al., 2018; Sadler et al., 2007). In Canada, a similar moniker of Science-Technology-Society-Environment (STSE) has been used for more than two decades in curriculum documents and has conceptual overlap with SSI (Pedretti & Nazir, 2011). For this research study, we prefer the term socioscientific as it succinctly asserts the entangled bonds amongst physical, conceptual, and semiotic systems found with complex scientific topics like climate change or pandemics (Fazio, 2020).

Our collective good is fortified when citizens are equipped to learn, evaluate, and respond to SSI that impact society (Aikenhead, 2006; Bencze, 2013; Norris & Phillips, 2003). In the geographic context of the study, the Council of Ministers of Education, Canada [CMEC] (1997), and provincial/territorial Ministries of Education (e.g., BC Ministry of Education, n.d.) have long advocated that schools strive to develop democratic and responsible science citizenship goals. Key to ensuring these important competencies in relation to reading and scientific reasoning is that students become immersed in experiences with texts that appropriately use scientific disciplinary literacy strategies to enhance learning of SSI-based texts (Pearson, et al., 2010; Stang Lund et al., 2019). Citizens must be able to engage in science-based reading from multimodal sources in their academic, professional, or personal life to address these societal issues and become scientifically literate (Yore, 2012). The call for schools to teach critical thinking to students related to science reading in multimodal and digital formats is mounting (Fazio & Gallagher, 2018; Organization for Economic Cooperation and Development [OECD], 2018; Ku et al., 2019). Continuing to do so requires research that addresses specialized science-based reading, critical thinking, and digital technologies for complex SSI issues such as climate change.

## Conceptual Perspectives

Reading multimodal texts for learning in science has garnered considerable interest from researchers and practitioners. In particular, the linking of science education and language (literacy)-based educational research has produced synergies that have brought value to researchers and teachers within the real-world contexts of schools (e.g., Fazio & Gallagher, 2019). While writing, reading, and oral communication modalities are important (and traditional) ways to organize disciplinary discourse, our current research perspective views multimodal learning as meaning-making in science *writ large* (Danielsson & Selander, 2016; Kress, 2009; Norris, 2011).

It has been known for some time that students learn more deeply from multimodal reading with texts and pictures than reading alone (Mayer, 2005). Added to this is the notion of technology-enhanced reading of SSI texts, which is a novel focus for this research topic. We circumscribe our research study with respect to conceptual perspectives on SSI issues and reading multimodal texts.

### Socioscientific Issues and Reading Literacy

The value of reading and writing in science programs is well-established (e.g., Cervetti & Pearson, 2012; Pearson et al., 2010; Tippett, 2010). Furthermore, there is unanimity regarding its benefit for students learning about SSI through reading, particularly in elementary grades (Boggs et al., 2016; Zeidler & Nichols, 2009). Key to ensuring amplified competency development when engaged in reading and scientific reasoning is to have students immersed in experiences that appropriately use literacy strategies to enhance learning of SSI-based texts (Stang Lund et al., 2019). One of the most pernicious SSI of our time is climate change because of global warming and its impact on social-ecological systems (NASA, 2020; Intergovernmental Panel on Climate Change [IPCC], 2022). Regrettably, the disconnect between scientific understanding of climate change and public knowledge is increasing, in part, due to confusing media and "fake" or erroneous multimodal science news reports (Scheufele & Krause, 2019). Additionally, this SSI topic is ubiquitous today because youth are exposed to climate change both in and out of school contexts (Field et al., 2020).

Recent commissioned polls across North America (Leger 360 Market Research 2018; Pew Research Center, 2019) regarding attitudes to science found that many adolescent respondents utilized three primary sources for scientific knowledge: schools (i.e., teachers), print resources (e.g., books or magazines), and the Internet. Clearly, science-based texts available in and out of school contexts (e.g., home) are critical to students' understanding of complex scientific issues such as climate change (Beach et al., 2017). SSI-based reading may be subsumed under the broad and established area of disciplinary literacy (Fazio & Gallagher, 2018; Goldman & Scardamalia, 2013; Goldman et al., 2016; Leu et al., 2017; Zygouris-Coe, 2014). Teachers often struggle to support students as they learn reading and writing *while* learning in the domain of science (Mason & Hedin, 2011) in addition to addressing ill-structured SSI topics (e.g., water pollution, immunization, climate change) (Britt et al., 2014). This learning is essential as building and activating background knowledge and vocabulary in science predicates the use of learning strategies and encourages students to read, write, and think like scientists (Fisher et al., 2009).

Engaging students in authentic tasks that are typical of critical thinking and inquiry in science, and enhance learning about SSI, supports domain-specific knowledge and vocabulary learning that are important for twenty-first-century challenges for schools (Parsons & Ward, 2011). For students, the acquisition of literacy skills is essential to support reading and writing for meaning-making in science (Gallagher et al., 2017; Cervetti et al., 2012; Fang, 2006). By situating literacy within a robust knowledge-building domain like science, opportunities arise that encourage students to synergistically explore scientific phenomena and build fundamental literacy skills (Bradbury, 2014). Empirical research provides evidence of the instructional efficacy of science *and* literacy integration interventions in elementary classrooms (e.g., Fazio & Gallagher, 2019; Goldschmidt, 2010; Patrick et al., 2009, Vitale & Romance, 2012).

Critical thinking is important for students, particularly when reading about SSI. While very popular in public educational discourse, defining critical thinking is still a work in progress in educational research because key conditions for successfully addressing it for education are lacking in terms of (a) the availability of a clear, specific, and operational definition, and (b) a deeper understanding of the natural cognitive bases of critical thinking (Pasquinelli et al., 2021). The importance of critical thinking when reading SSI is analogous to the numerous calls regarding critical thinking and "fake news," particularly during the COVID-19 pandemic and other global political events where media and communication technologies are the primary sources of information for adolescents (Horn & Veermans, 2019; Ku et al., 2019). For this study, we used Pasquinelli et al.'s (2021) definition of critical thinking and its manifestation when reading SSI texts as, "the capacity of assessing the epistemic quality of available information and—as a consequence of this assessment—of calibrating one's confidence in order to act upon such information." (p. 5). Foundational to this study is how meaning-making via electronic science texts builds on the notion that language is an essential cognitive tool for learning science. Thus, meaning-making in science via multimodal literacy represents a unique hybrid of natural language, contextualized by visual representations and other symbols, embedded in language specializations and actions that are situated in technological environments where science is learned (Lemke, 2004).

### Reading Multimodal Texts

Over the past two decades, transformations in digital technologies have shaped students' learning, their interactions with others, and their perceptions of themselves (OECD, 2018). Digital technologies have given rise to new types of multimodal learning, particularly in reading texts (Fazio & Gallagher, 2018; CMEC, 2019). The presentation of the text in digital forms refers to, "audio, visual or multimodal texts produced through digital or electronic technology which may be interactive and include animations and/or hyperlinks" (Definitions section, para. 1; New South Wales Government Education, n.d.). Alternatively, *multimodal texts* refer to texts that utilize two or more means of communication (Wang et al., 2020). Indeed, all meaning-making is multimodal (Kress, 2009), but we recognize that there is a dynamic meaning ecology for the term, *multimodal.* For our study, we define multimodal as texts that utilize different communication modes (e.g., text, images, hypertexts) that in combination convey meaning and require the reader to interpret non-linear texts differently than print-based texts (Liu 2015; New South Wales Government Education, n.d.). This aligns with the term, *multimodal representations*, which refers to science learning using one or more integrated representation of language, depiction, and symbols (Prain & Waldrip, 2006). Herein, we acknowledge that there remain ambiguities in the research literature when defining multimodal texts but contend that the participants in this study were reading multimodal texts using digital technology (i.e., iPads). Multimodal texts need to be navigated as a reader's attention often shifts between images and texts. Digital images in multimodal texts often convey rich information and engender meaning-making processes (Bezemer & Kress, 2008). Coupled with the meaning conveyed through texts, this can be challenging for readers to coordinate different resources to make meaning from multimodal texts (Lemke, 1998). Moreover, access to copious information in multimodal texts often engenders insufficient critical thinking (Kenyon, 2008). Students may be misled by biased or "fake" representations particularly on digital platforms in this post-truth era (Wineburg et al., 2016). This has been documented in a recent review of the literature (Rouet et al. 2021) on how post-secondary students evaluate the competency of knowledge that they read based on the originating source of the information and how students gravitate to sources of knowledge when faced with contradictory information.

In this context, cultivating students' critical thinking competencies when reading SSI-based texts can help them capitalize on available digital resources and better understand the world around them (OECD, 2018). Despite the notion that contemporary learners possess fluency in digital language, studies have disputed claims of this "native" expertise. For example, Zhang's (2012) analysis of students' online scientific reading found that their reading was cursory, opportunistic, and required extensive guidance. As well, supporting students to make meaning in a discipline like science is critical to leveraging the affordances of multimodal texts (Danielsson & Selander, 2016). Spencer et al.'s (2020) recent scoping review of interactive multimodal texts with students identifies features and factors relating to interactive digital texts and student experiences. However, the authors found it difficult to develop specific recommendations due to the wide-ranging and disparate research that had been conducted.

The change in the delivery of science content from paper to digital display devices (i.e., multimodal reading) has altered the cognitive processes that readers use to approach science-based texts (Michalsky, 2013; Yen et al., 2018). To read and comprehend subject content (such as in science) in multimodal texts, readers need to appreciate text structures, navigate complex resources, and engage social, affective, and cognitive dimensions (Danielsson & Selander, 2016). To this end, Danielsson and Selander (2016) proposed a model to guide educators and readers as they understand multimodal texts' foci, broadly categorized as general structure, interaction between textual parts, figurative language, and the values expressed or implied (from translation, Danielsson and Selander 2016). This model describes how readers engage with discipline-specific multimodal texts and was used as a general framework for data collection and analysis in the current study. In the data collection, student participants' understanding of disparate science texts was garnered through discussions related to the text format, content, and message impact.

Failure in self-regulation during online science reading may be attributed to students' lack of appropriate metacognitive knowledge, causing them to misjudge their level of understanding of digital text and, in turn, terminate prematurely or negatively augment their reading efforts (Lauterman & Ackerman, 2014). Compounding these challenges is the recent proliferation of diverse online scientific information, coupled with declining trust in institutions and scientific expertise (Social Sciences and Humanities Research Council [SSHRC], 2018). Furthermore, the confluence of psychological processing by students of science-based text and dealing with contentious topics (Wolfe et al., 2013) is a novel area of inquiry. Collectively, these claims bring to the forefront our endeavor to support critical thinking while reading SSI topics using multimodal texts.

Our research objective for this exploratory study was to understand how adolescent students engage in the reading of contradictory multimodal texts about climate change using their naïve competencies to understand factors that affect their critical thinking. Accordingly, we asked the following research questions: (a) how do adolescent students engage in critical thinking with respect to a climate change topic when presented as contradictory multimodal texts? (b) Which text features associate with students' critical thinking processes with respect to SSI? The significance of this exploratory study is that it begins to address the challenges of public understanding of science as manifested in integrated science and language contexts with adolescent students.

## Methodology

### Overview and Research Context

This study utilized a qualitative research approach suited to naturalistic methods of inquiry (Creswell, 2014). Using a within and individual case design (Yin, 2009), this descriptive research study involved two detailed 60-min observations of six adolescent students (i.e., student cases) reading two different texts about coral reefs, climate change, and pollution from two contrasting perspectives designed by the researchers (see supplemental figures ES1, ES2) and using the same think-aloud protocol. The rationale for the protocol and contrasting text is that when individuals read complex issues, like climate change, they are encountering information that is complex and potentially conflicts with their prior knowledge. Accessing two contrasting texts (sometimes referred to as refutation texts) and the think-aloud protocol in tandem makes the conflicting knowledge more salient for readers to critically process the scientific reading information (Danielson et al., 2016; Rapp & Braasch, 2014).

## Participants' Profiles

Six adolescent volunteers ($\bar{x}=11.5$ years) participated in the study. These individuals were recruited from a university summer enrichment program in 2019 at the registration area located on a Canadian university campus. Both parents/guardians and students consented and assented to participate in this study verbally and in writing. University ethics clearance was obtained prior to collecting any data for this research project.

Students were surveyed to obtain demographic and background scientific knowledge on climate change topic. Survey items were adapted from the *Trends in International Mathematics and Science Study (TIMSS)* student context questionnaire (Martin et al., 2016) to provide a qualitative descriptor of the frequency of participants' use of computers or tablets for school purposes, whether students use the internet for schoolwork, and their attitudes toward science and knowledge of climate change. As a means of assessing students' background knowledge of the topic (climate change), a seven-question, multiple-choice assessment was administered before their text reading (for example, question 2: *What is the primary energy source for the Earth's climate*? Possible answers: a. *heat from the Earth's interior; b. the sun; c. electricity generating power plants; d. oil and gas*). This 10-min survey and questionnaire was administered in a one-on-one setting.

Based on these two instruments, participant profiles were created (see Table 1) to provide contextual comparisons of their critical thinking of SSI-based texts with respect to their antecedent factors (e.g., background knowledge).

The profiles indicate a pervasive use of a computer/tablet and Internet by all the participating students. The participants hold positive attitudes to science which is consistent with surveys of Canadian adolescent students (Ipsos Reid, 2010), and that older students have more background knowledge about climate change. While the study had a small random sample of adolescent participants, the data suggests that this is a reasonable representation of students from the region where the research was conducted.

## Data Sources and Methods

After their surveys, students were given two multimodal texts to read on an iPad focused on coral reef damage. The novel topic of these texts was chosen as the provincial science curriculum has not extensively addressed the impacts of climate change with these adolescent student participants. One of the texts represented a

**Table 1** Student participant profiles

| Participant | 1 (age 11) | 2 (age 11) | 3 (age 11) | 4 (age 14) | 5 (age 10) | 6 (age 12) |
|---|---|---|---|---|---|---|
| Computer/tablet use for schoolwork | High | Moderate | High | Moderate | Moderate | Moderate |
| Use of WWW for schoolwork | High | Moderate | High | Moderate | High | Moderate |
| Attitudes toward science | Very positive | Very positive | Very positive | Very positive | Very positive | Positive |
| Background knowledge of climate change | Below average | Well below average | Above average | Above average | Well below average | Well above average |

viewpoint on coral reefs and its impact due to climate change (see ESM 1), whereas the second text was an alternative and contrasting viewpoint (not mentioning climate change or global warming) on the same topic of coral reef damage caused by human pollution (see ESM 2).

The refutation texts were authored by a content expert and validated by middle school educators. Both texts were matched in terms of text readability and multimodal features (e.g., images, hypertexts, formatting). The authors have prior research experience with text readability and multimodal features of science-based curricula and texts (Fazio & Gallagher, 2014; Gallagher et al., 2017 2014, 2017); accordingly, the two texts used in this study were matched for these qualities. It should be noted that the multimodal text qualities generally align with Danielsson and Selander's (2016) model for working with multimodal texts in education, including general structure, interaction between textual parts, writing style such as figurative language, values, and text readability appropriate for the age of the participants in the study. For example, two of the five images were identical and both included text features such as captions, sub-headers, glossary, and references providing participants with a general structure, and interactive coherency between both texts so that they could critically read both multimodal texts. It was necessary for these texts to be constructed specifically for the purpose of this study to control for the novel topic, viewpoints, text readability, and multimodal features for the student population in the study. Please refer to ESM 1 and 2 supplemental materials for the student texts.

We sought to assess critical thinking when reading with prompts to generate text processing responses (e.g., evaluating, monitoring, predicting) rather than just literal text processing prompts typically posed to students (e.g., main idea, fact identification). When comparing reading assessment processes, Scott (2008) determined that think-aloud processes generated a greater number and range of text processing responses, including personal interaction with text and metacognitive processing, when compared to post-reading questionnaire or error detection techniques. For this reason, a think-aloud protocol (see Table 2) was used with questions to elucidate how adolescent readers negotiate and critically comprehend (see Coiro, 2011) contradictory SSI-based texts. The questions in the think-aloud protocol were designed to prompt the student participants in critical thinking before, during, and after reading as well as trigger high-yield comprehension strategies such as visualizing, summarizing, reflecting, and making connections when examining multimodal texts.

To begin the think-aloud procedure, a member of the research team individually modelled this process with a sample of unrelated text. Following this, the students read the texts and were then prompted with questions using the pre-designed think-aloud protocol. The students read the text regarding climate change and coral damage first (ESM 1), followed by the coral damage and pollution article (ESM 2). There was a break of a 1 day between reading the two texts because students were involved in program activities at the university. Digital audio recordings captured the think-aloud episodes between individual students and a researcher; in addition, the researcher took observational field notes. All recordings were transcribed for discourse accuracy and the transcripts assisted in coding the responses. Finally, all transcripts and codes were reviewed collaboratively by

**Table 2** Think-aloud protocol

| Predicting prompts: | |
|---|---|
| 1 | *[Prior to reading]* Describe what you know about _____? |
| 2 | *[Prior to reading]* Read the sub-headers for this multimodal text, describe what do you predict this text will be about? |
| **Questioning prompts:** | |
| 3 | Why did the author of the text discuss ___? |
| 4 | What did you learn about ___? |
| 5 | How does ___impact ___? |
| 6 | Did you use context to understand the vocabulary of this text passage? If so, what do "[disciplinary vocabulary word #1]" and "[disciplinary vocabulary word #2]" mean? |
| **Visualizing prompt:** | |
| 7 | When asked to visualize ______, describe what you picture… |
| **Personal response prompts:** | |
| 8 | Describe your reaction to the scientific information in this text. How do you feel after reading it? |
| 9 | What is your favorite part of the text passage? |
| **Clarifying prompts:** | |
| 10 | Was there anything in the multimodal text that you didn't understand? If so, describe what was difficult to understand |
| 11 | Reflect on the [one of the multimodal text], what did you not expect to read and learn about? |
| **Summarizing prompts:** | |
| 12 | What is this text passage mainly about? Summarize it for me |
| 13 | What is the most important idea in the text passage? |
| **Reflecting prompt:** | |
| 14 | After reading this text passage, what do you still wonder about? |
| 15 | Is it easier or more difficult to read this as a multimodal text using the tablet? |
| **Making connections prompts:** | |
| 16 | How does the information that I just read about fit in with what I already know? |
| 17 | Have you ever ___? If you have, describe how you ___. If you have not, then ___? |
| 18 | How did you use the text features (e.g., photos, headers, bullets) to help you read the multimodal text passage? |
| 19 | *[After reading the second text passage, the researcher will ask]* After reading both text passages, what are the connections between the two? How are the text passages similar and how are they different? |

the researchers (authors) using NVivo 12™ software (QSR International, 2018) to ensure coherency and consistency between the codes and transcribed texts.

### Data Analysis

First, NVivo software was used to assist in the data organization and analyses to identify frequently expressed words and phrases within all the data. Then, intentionally looking for specific concepts to deductively code (Saldana, 2009), the students' responses to each of the think-aloud questions (i.e., predicting, questioning, visualizing, personal response, clarifying, summarizing, reflecting, making connections) were extracted by each of the researchers. They each used an inductive coding strategy (Charmaz, 2014) to generate categories from students' responses that related to their affect, text features, cognitive dissonance, analyses of the argument, and scientific knowledge. These five categories aligned with prerequisites for reading multimodal texts as identified by Danielsson and Selander (2016) (i.e., text structures, resources, social, affective, and cognitive dimensions).

With these categories as a framework, there was a second round of analyses to identify themes that were implied by participants' emotional elicitation statements. In this way, Danielsson and Selander's (2016) affective and cognitive dimensions were used to identify pertinent statements such as the following: Researcher: Describe your reaction to the information in the text. How do you feel after reading it? Participant 7: "Mad. A little, sad. Disappointed." and similarly with Participant 4: "Yeah, like I feel like if they understood like, what would happen if we lost it, they would probably care more." Further exemplified by Participant 1: "Interesting…I just never really knew that much about corals." Within this theme, codes were inductively developed and used to classify emotional engagement such as happy, curious, worry, sadness, hope, or frustration.

Afterward, the category related to the text features was analyzed and a theme was created that captured students' mentions of the glossary, images, headers, and bolded key terms. Next, there was an analysis of the categories that captured students' cognitive dissonance and argument analysis statements, specifically noting when students provided skeptical, evaluative, uncertain, or novel responses about the texts' claims and descriptions. The final round of analyses identified a theme related to prior scientific knowledge connections participants made throughout their think-aloud responses.

There were notations used to delineate which of the two texts the students were responding to, allowing their responses to be compared. As well, attention was paid to the final think-aloud prompt after reading and comparing both texts. Each round of coding and categorizing included a full read-through of all transcripts by the researchers, their independent coding/categorizing, and negotiating interpretations of the codes and categories into themes. The range of inter-rater reliability of applying the codes for the researchers ranged from 85 to 95%. Exemplar quotes from the transcripts are thematically presented in the "Results" section below.

## Results

During the two sessions with each of the participants, both observational field notes and audio recordings of their responses to the think-aloud protocol were recorded. The analyses of these data were thematically coded and provided insight into how students engaged with the two texts; we focus our results' presentation on the responses from the students. Participant numbers identified in the quotes below correspond to the profile number found in Table 1. The quotes from the participants also identify the actual text being referred (as parenthetical phrases) where appropriate. The six participants engaged in the two think-aloud procedures produced 341 analysis units in total. The mean unit analysis per student was 57, with a range of 50 to 65 analysis units per student. Notably, the oldest student (aged 14) produced the most coded units (65). Below are excerpts of the coded data organized into thematic categories, providing an illustration of the participants': *background knowledge prompted by prediction; emotional engagement; cognitive dissonance; argument analysis; impact of visual images*.

### Background Knowledge Prompted by Prediction

The first two prompts in the think-aloud protocol asked the student participants to predict what the texts would be about and what they knew about this topic. These types of questions attempt to explicitly elicit background knowledge based on minimal prompting (e.g., images, sub-headers) and are a good indicator of topical background knowledge. Overall, the participants had very little background knowledge regarding coral reef biology. Below are some data excerpts:

The lack of knowledge displayed by the participants about coral animals is understandable given that it's not addressed explicitly in the provincial science curriculum of the participants, and none of them had travelled to a location where corals inhabit the local oceans. In contrast, 100% of the participants had heard of "climate change" or "global warming." Therefore, when participants' responses to these prediction prompts related to the topic of coral reef health are compared to their overall background knowledge of climate change, it was apparent that a lack of pre-existing understanding of the text topic would not confound the responses to the subsequent questions in the think-aloud protocol.

When prompted using the other questions in the think-aloud protocol, the student participants were asked to communicate both their literal and inferential understandings. The literal prompts required participants to question, clarify and summarize what they read. The inferential prompts encouraged the participants to visualize, reflect, make connections, and respond personally to the text. Their responses and the observational field notes were coded for insight with respect to student engagement with the texts. These included expressions of emotional engagement, cognitive dissonance, argument analysis, and use of images to impact comprehension.

### Emotional Engagement

The differences between the two texts were interpreted in emotional ways by the student participants. They viewed the topic of coral well-being from a position of hope versus despair. They preferred to avoid or selectively ignore the text that described the true impact of climate change on coral well-being. For example:

> Participant 1: …with the polluting text (pointing to text not mentioning climate change), I felt like this one was quicker to read. They're different because, this one (pointing to text not mentioning climate change), there is hope for corals. This one (pointing to text referencing climate change) doesn't have that.
> Participant 2: …well, this text (text not mentioning climate change) made me feel less worried (than the text referencing climate change) because they talk about that coral bleaching doesn't kill the coral. And that makes me less worried, because that means it won't take as much effort to help the corals because some corals will live through it, but some won't.
> Participant 4: …last time I felt shocked (text referencing climate change), I think this one (text not mentioning climate change) I feel like, more like at ease with what's happening. Cause' last one (text referencing climate change) it was just like, very like, trying to make it seem very bad. But this one's (text not mentioning climate change), making it seem like it's not even that big of a deal.

The students did not want to readily accept the information about the impact of climate change on coral well-being. When presented with information that was less foreboding, the students wanted to believe that this was true and were emotionally invested in this alternative. Indeed, new evidence from research on critical thinking (Lombard et al., 2020) suggests that emotional engagement might be integral to understanding and thinking critically about SSI issues. In response to the first research question, adolescents become emotionally engaged when reading about climate change in the contradictory multimodal texts.

### Cognitive Dissonance

The realization that informational text might be inaccurate or biased came as a surprise to the participants who recognized differences between the two contradictory texts. There was a certain amount of naivety and trust in the veracity of the written texts. As well, the participants tended to minimize the gravity of the implications of what was written.

> Participant 2: (Thinking about both texts) Why would they, why would they like (pause), if it's not real then why would they say it's real? Cause that would just be silly lying about something like that.
> Participant 4: I learned that coral bleaching is a normal part in like, the coral's life. In the (text referencing climate change article), I thought it meant it was like dead when it was bleached, but this (text not mentioning climate change) just

explained it's normal for it to turn white because it always goes back to colorful. And it said that it, they don't die when they turn white. So, I didn't know that.
Participant 4: To be honest, I don't really know which (article) makes more sense, because they look like they're written by the same author, so maybe just the last text they were trying to make it sound worse than it actually was or something.
Participant 6: Well they both (articles) talk about the same things, but they're different. Like they have different perspectives. Like, for coral bleaching, it can come back, like you don't need to like, chop off some of the parts and it will grow back, it's just, it'll come back over time, and if they do die off then you can just grow new ones.

For most of the participants, the cognitive dissonance that ensued after reading the two texts from different or contrasting viewpoints went unchecked: the student participants defaulted to believing what they read and viewed in the texts. This is an example of the need for explicitly teaching critical thinking skills with the support of the affordances of digital texts (Gökçearslan et al., 2017). The students in the study did not fully engage independently in critical thinking when presented with contradictory multimodal texts, but only after some prompting with the think-aloud procedure. These findings showcase how these adolescents attempted to reconcile the contradictory multimodal texts, exposing their cognitive dissonance and naïve practical epistemic views during this task (Duschl & Jiménez-Aleixandre, 2012).

### *Argument Analysis*

Some of the participants clearly missed the main argument in the texts and failed to connect the coral bleaching as a primary issue because of climate change (see ESM 1) or recognize secondary issues such as pollution (see ESM 2). The information in the two texts was taken at face value despite the veracity of the questions in the think-aloud protocol.

Participant 6: The first one (text referencing climate change) is more scientific and made more sense, because I've heard more about carbon dioxide, and I understood kind of what it does for climate, which the (text not mentioning climate change) was more about pollution and how pollution does it (coral bleaching), it didn't really 'cause' it, it had a climate change part but…the pollution didn't really go with the climate change.
Participant 3: Apparently, it's saying (text not mentioning climate change] that it's a normal cycle; it just comes for a little while and then those creatures just comes back…. maybe from the last text (text referencing climate change) saying that they bleach also. Well in this one text (text not mentioning climate change] also they said they bleach too because of environment changes.

It was somewhat surprising that the information in these texts was comprehended at a surface level without much interrogation. A think-aloud protocol typically prompts readers to think critically while reading so as to support comprehension

(Coiro, 2011). These students appeared detoured from engaging in fully appraising the climate change phenomenon in these two texts and primarily focused on the coral bleaching phenomena. These findings support similar research examining textual and individual factors on source-content integration when reading digital texts (Stang Lund et al., 2019).

### Visual Image Impact

Overwhelmingly, observations of their reading and the participants' statements exemplified their usage of visual images to support their comprehension of the scientific text content. Their haptic movements on the iPad allowed them to go back forth from images, hyperlinks, and text during reading. This is a typical strategy for supporting the comprehension of multimodal text with image-based text that is commonly taught to students in elementary classrooms.

> Participant 6: Well, I didn't really know what they meant by coral bleaching. I kind of look at the picture and I saw like, it's taking away all the stuff from the corals.
> Participant 1: … I didn't expect this [points to coral image in text] to be there because it's the exact same thing as in the last one (text referencing climate change) pretty much….because, I 'dunno', I thought it would be different like a different point of view or something….I think the same person made them, because they have the same style for everything….the same pictures for a lot of them.
> Participant 5: Looking at the pictures to see if it was, some things that are actually true (reference to coral bleaching images).

As illustrated above, the student participants were relying heavily on images as critical multimodal text features to inform their understanding while reading. Like the descriptive prose in the texts, the images in the texts were taken at face value, and the students ascribed great weight to what they viewed in these images.

### Summary of Results

The research questions for the study asked how adolescent students engage in critical thinking of a climate change topic when presented with contradictory multimodal texts, and which text features correlate with their critical thinking. Our analyses revealed that there is an interconnected and nuanced relationship amongst many text and individual factors when adolescents engage in critical reading of SSI multimodal texts. This includes the adolescent students' background knowledge on climate change and coral reefs, emotional investment in the climate change topic, "trust" in the authorship of informational text, and the texts' structure using technical vs. colloquial language. In response to the second research question, visual images impacted the critical thinking of participants when engaged in reading SSI-based texts. These semiotic resources combined to influence students' interpretations of the SSI-based texts descriptions and claims as expressed in the think-aloud data. Furthermore, the identified themes in the "Results" section are conceptually interconnected, reflecting the interdependent cognitive and emotional engagement of the individual readers during critical reading of SSI-based multimodal texts.

## Discussion

A think-aloud protocol was used to describe how adolescent readers negotiate and critically comprehend contradictory SSI multimodal texts. Their responses illustrated how they evaluated new information about climate change by attempting to reconcile some of the contradictions in what they had recently read and relating it to their background knowledge. Initially, this was done by asking the participants to make predictions about the topics addressed in the texts and relating this to what they did and did not know about climate change. Additional prompts elicited responses that thematically describe their negotiation of these contradictory texts with each other. These themes were: emotional engagement, cognitive dissonance, argument analysis, and impact of visual images. We subsequently discuss these themes as interrelated constructs in relation to other studies.

While emotional engagement with fiction vs. non-fiction texts favors the former (Oatley, 2017), the non-fiction texts in our study elicited emotional responses (e.g., hope, relief, shock) during the think-aloud procedure. This result is in part from the adjacent presentation of the two contradictory texts (text referencing climate change vs. text not mentioning climate change), but also showcases evidence of emotional engagement and comprehension that can impact conceptual change and learning in science (Sinatra et al., 2014). This process entails the epistemic cognition of learners and highlights the importance of emotion (Muis et al., 2015; Pekrun et al., 2017) during reading. We contend that this finding is an affordance of our study and provides fodder for novel research in science education and reading complex SSI-based multimodal texts that evoke emotional responses (Roozenbeek & van der Linden, 2019; Thacker et al., 2020). Certainly, educational and public discourse surrounding climate change contribute to heightened emotional responses from participants. Students in this study overwhelmingly pointed toward a preference for the more hopeful text (i.e., multimodal text on pollution – ESM 2) that did not reference climate change. This text offered a problem–solution orientation to coral bleaching that was plausible to the students and avoided a grand "narrative" of climate change, global warming impacts, and mitigation requirements to reverse coral bleaching. While specific refutation texts have been used in science education to address conceptual misconceptions (e.g., Danielson et al., 2016; Tippett, 2010) further research is needed with respect to text factors impacting the emotional constructs of individuals reading non-fiction SSI-based texts, and impact on adolescent comprehension, decision-making, and future actions.

The cognitive dissonance that some of the participants experienced was inextricably linked to their emotional reactions when reading the texts. Some of the participants were able to identify conceptual inconsistencies in the arguments stated in the texts and exhibited cognitive dissonance with the focus of the articles. This ability seemed to correlate, to a certain extent, with background knowledge on climate change and age of the participants (e.g., Participant 6's responses in the "Results" section). When dissonance occurs in relation to an authority-holding enterprise such as science, readers can be in disbelief and retract to previously held notions of truth (De Meyer, 2017). The participants in this study tended to minimize the foreboding nature of the text mentioning climate change and overlooked the conflicting arguments in the texts. Dissonance was evoked by the multimodal texts that appeared credible yet contradicted each other, and this was unsettling to some participants (e.g., Participant 2's response in the "Results" section).

The ability of students to construct and evaluate arguments is central to critical thinking in science (Ennis, 2016) because participation in argumentation activities improves skill development necessary to deal with complex SSI topics like climate change (Dawson & Carson, 2017). The think-aloud prompts in this study required participants to compare and evaluate the texts. However, students did not have enough time to process their responses, as in many argumentation studies where individuals are required to write out their evaluation of arguments from their reading (Ferretti & Graham, 2019). Together, studies regarding student background knowledge (Wang & Buck, 2015) and argumentation assessment with respect to age or learning progression of students (Larson et al., 2004; Song et al., 2013) might be considered as one way to describe the developmental abilities of learners to critically think about scientific arguments. Given that this study was not a pedagogical intervention, the results nevertheless illustrate a preliminary argument evaluation by participants when prompted with a think-aloud protocol. This activity points to a procedure for future development of a detailed learning progression of SSI reading of texts and argumentation competency development appropriate for educators in school contexts.

Visual features in non-fiction science texts are integral to communicate meaning in science, and when well-chosen they illuminate information in ways that often words alone cannot express (Donovan & Smolkin, 2002). Capitalizing on the value of visual features, a quintessential feature of multimodal texts, readers can use images to assist with decoding and to enhance comprehension. Using visual features to enhance multimodal comprehension is a strategy to enhance meaning derived from SSI-based text (Moss, 2015). Given their educational experiences, it was a natural default for the adolescent readers in this study (who might have been unfamiliar with the vocabulary or the concepts) to rely on images to comprehend disparate scientific content. In elementary classroom instruction, students are often taught a reading strategy to glance at the images prior to and during reading (Kelley & Clausen-Grace, n.d.). Furthermore, the visuals in texts are often used in relation to the print as the participant is a "viewer-reader" consuming both modalities (Moss, 2015). In summary, the results highlight the need for educators to continue to explicitly teach students how to critically view, read, and evaluate scientific information for effective meaning-making.

## Limitations

This study was exploratory with a limited sample of adolescent participants and therefore not representative of an entire population. The results of the background knowledge assessment and think-aloud procedure with this cross-section of participants (age 10–14 years) indicate a need for a more comprehensive and developmentally representative sample. This study was also limited in duration to two administrations with two multimodal texts. While it was established that participants did not have prefatory knowledge related to the texts, additional exposures to the same procedure (with different texts) would be insightful. Finally, a breadth of topics on SSI issues should also be explored as this study only utilized texts related to climate change, pollution, and coral damage.

## Conclusions and Implications

It cannot be assumed that contemporary learners possess fluency in multimodal and digital reading, as it has been documented that students' online and digital scientific reading is cursory, opportunistic, and requires extensive guidance (Zhang, 2012). Furthermore, the need persists for educators to teach critical thinking to adolescent students as it relates to science reading in multimodal formats (Fazio & Gallagher, 2018; OECD, 2018; Ku et al., 2019). Consequently, research that addresses specialized science-based reading, critical thinking, and digital technologies is timely. Thus, an important goal of this study was to determine how adolescent readers negotiate and critically comprehend SSI-based multimodal texts focused on climate change impacts.

Elementary and secondary teachers often struggle to support students learning the processes of reading *and* writing in science classrooms (Drew & Thomas, 2018; Orr et al., 2014). This challenge is exasperated when dealing with ill-structured and complex topics like climate change. This is an important topic for educators and researchers alike since adolescents are currently embracing these topics outside of school contexts (Bandura & Cherry, 2019). These findings contribute to identifying important lexical aspects of texts as educators incorporate different forms of multimodal texts into classroom instruction when teaching about climate change and other socioscientific topics. Importantly, this research is still in its infancy (CMEC, 2019). Meaningful studies that use think descriptions are necessary to begin to understand how these reading processes are manifested with adolescent students; and in turn, influence how science and language teachers engage with students using multimodalities. Since learning operates on cognitive and affective dimensions, the style, text structure, and authors' inferred values contribute to multimodal text comprehension (Danielsson & Selander, 2016; Stang Lund et al., 2019). Furthermore, the effects of epistemic cognition and emotions on adolescent students' critical reading of SSI multimodal texts is an important path for future research, which has some backing from studies with students in higher education contexts (Chevrier et al., 2020; Kammerer et al., 2021; Muis et al., 2015). Clearly, there has been a shift to multimodal text reading that requires learners to assess and evaluate textual scientific knowledge claims using prior knowledge, multimodal and multi-text strategies (Braasch & Braten, 2017; Tang, 2020; Tseng et al., 2021). This is likely to have an enormous impact on science teaching and learning as we continue into the twenty-first century. Recognizing the importance of pedagogies that reflect the twenty-first-century learner and their socioscientific contexts implores us to continue synergistic science and literacy research in elementary, secondary, and postsecondary settings.

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