Introduction

Canada is currently in the development phase for a national earthquake early warning system (EEW) that will operate in regions including British Columbia (a natural geographic extension of the US-based EEW system), and Ontario, Quebec, and New Brunswick in the east. To ensure effectiveness, the public needs to understand the alert message when they receive it and immediately know what to do, such as “Drop, Cover, and Hold On”. A challenge with EEW broadly is to avoid end-user fatigue while maintaining system confidence. Maintaining these goals is not limited to the system and its operations, but also with how the public interprets the alert, especially as alerting strategies are continually tested and fine-tuned [e.g., *McBride et al.*, 2020].

The Canadian EEW system is based on technology already implemented in the United States by the U.S. Geological Survey (USGS) called ShakeAlert®. ShakeAlert® depends on the quick detection of the P-wave and determination of an earthquake’s location, magnitude, and intensity. If an earthquake above a certain magnitude threshold is detected, the goal is to send an alert out to potentially affected communities who may experience shaking above a certain intensity threshold before the S-wave is felt. The USGS finds that various members of the public have difficulty understanding when and why they receive an alert and explaining the situations in which they do not, which therefore requires post-alert messaging [e.g., *McBride et al.*, 2020]. A major reason seems to be a lack of public understanding around earthquake magnitude and intensity. These terms are commonly used in everyday lexicon, yet have very specific scientific meaning in seismology. It is important that the system users have reliable understandings of these concepts because the end-user response to the system relies on specific intensity and magnitude threshold criteria being met prior to generation of an alert.

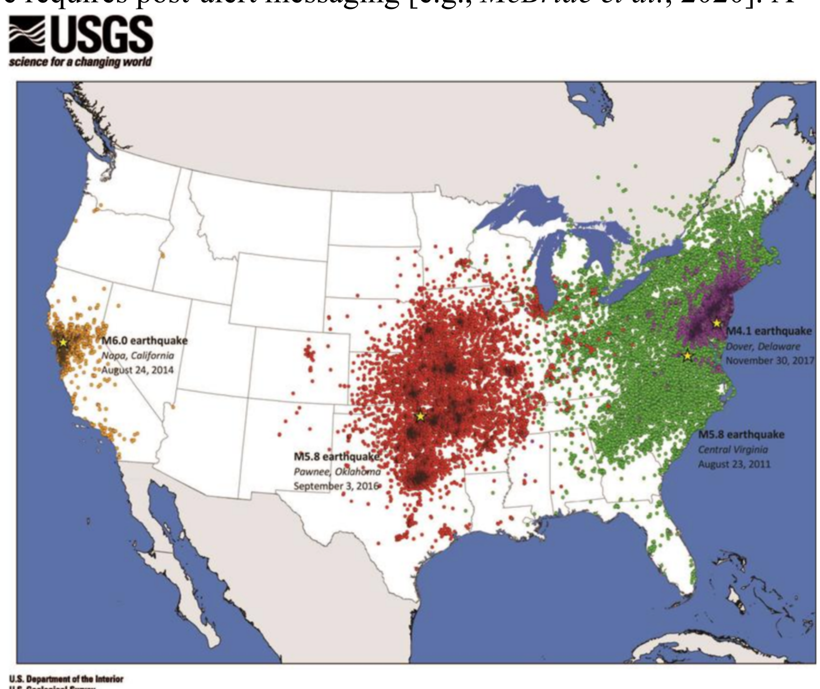

Figure 1: Map of USGS “Did You Feel It?” data shows that earthquakes east of the Rocky Mountains [eastern North America] are felt over larger areas than earthquakes in the West [western North America]. Earthquakes of the same magnitude have very different intensities, depending on the location within North America. Credit: Eric Jones, USGS

The Canadian EEW system will be implemented along both eadtern and western provinces, and because of the difference in geology between these two regions, the same magnitude earthquake will produce very different intensities (Figure 1). The USGS uses the saying “Fewer quakes but bigger stakes in the east" (https://www.usgs.gov/news/east-vs-west-coast-earthquakes; last accessed 4 November 2021) because earthquakes in eastern North America are more widely felt than earthquakes in the west. Thus, the development of the Canadian EEW system must address education and communication around magnitude and intensity, as these issues will have greater meaning and impact for Canada, perhaps compared to any other EEW system around the world.

Addressing this problem will require a strong public education initiative, one that will reach all potential end-users of the EEW system. Our project proposal includes students and faculty from the University of Calgary who will use a three-pronged approach to specifically address the earthquake magnitude/intensity question. The involvement of students will help to develop an educated and trained workforce around EEW in Canada. The Calgary team will work to discover why public understanding of these scientific concepts does not reflect their scientific meaning, and how to best mitigate the issue(s) through appropriate education and communication strategies, to include effective EEW alerting and post-alert messaging strategies. In-kind personnel support is provided by the USGS ShakeAlert project team (de Groot and McBride), James Madison University (Pyle, under USGS contract), and the Incorporated Research Institutions for Seismology (IRIS; Hubenthal and Sumy, Sumy under USGS contract). Collectively, we will implement a linguistics approach, a historical approach, and a sociocultural approach to magnitude and intensity misconceptions, as described below.

1. The Linguistics Approach

Work in the field of cognitive linguistics (*Lakoff & Johnson*, 1980; 1999) and embodied cognition (*Clark*, 2011; *Shapiro*, 2011) demonstrate that most of our understanding–and therefore, our communication–is metaphorical, with its basis in concrete sensory information. Importantly, metaphors are effective because they highlight certain aspects of the target concept. However, they also hide aspects, as well. Novice learners, who think differently about scientific concepts than experts (Clement, 2008) are less likely to discriminate between what is highlighted and hidden–what they should pay attention to and what they should not–and therefore can develop understandings about the target concept that do not match intended meaning.

For instance, *Dolphin and Benoit* (2016) found that the tectonic plate metaphor was inhibiting students' understanding of earthquake occurrence because their experience with plates was not as large portions of the earth's lithosphere, but as ceramic dinner plates, which they considered as separate and brittle. This caused them to think that earthquakes happened when tectonic plates were pushed together and collided. Understanding how concrete experiences influence how we think of abstract concepts through the use of metaphor can then help us direct thoughts of learners better (*Amin*, 2015; *Beger and Smith*, 2020). For instance, in the example just given, *Dolphin and Benoit* (2016) generated a new metaphor, the lithosphere is the skin of the earth. In this case, the skin is the source for the metaphor projected onto the target, lithosphere. This metaphor highlights the wholeness of the lithosphere of the earth and its elastic properties. Importantly, everyone has had many concrete experiences with their skin. They can also use shearing, compressional, and to some extent tensional forces to produce analogous deformation on their skin.

We **propose** to examine various media (to include news and social media) to: 1) determine how the public (learners) understand earthquake magnitude and intensity by identifying the metaphors they use (*Steen*, 2007; *Steen et al.*, 2010) when discussing these concepts; and 2) identify what metaphors learners are exposed to that could influence how they think about the target concepts (*Bock von Wülfingen*, 2020; *Williams Camus*, 2020). A proposed target is to investigate social and news media around any earthquake where a USGS ShakeAlert-powered alert was sent to the public to untangle confusion around real-world occurrences with EEWS that are easily transferable to Canada. Our **intended outcome** is to create knowledge of how the concepts of earthquake magnitude and intensity are understood by the public and how they are framed by teaching and other media sources, then to use that knowledge to develop the most effective linguistic tools (metaphors) for facilitating the public's reliable understandings around these concepts. EEWS public education and communication campaigns can use this information to better craft alerting and post-alert messaging.

2. The Historical Approach

The use of the history of science to teach science and about science began in the mid 20th century (*Conant*, 1947). The reason is that with the history of science, students can also learn about the process of science (*Matthews*, 1994). One effective vehicle for introducing and using the history of science for teaching science is the historical case study (*Allchin*, 2011; 2020, *Dolphin et al.*, 2018). Using historical case studies gives students the opportunity to experience science-in-the-making (*Latour*, 1987) and help them to develop more reliable mental models of target concepts. By using the case study, learners would develop their model of the target concepts similar to how the original scientists did, highlighting the rationale for the model, and giving the learner a stronger foundation for their understanding. Dolphin has restructured an introductory geology service course to highlight the historical development of three foundational geological concepts: the earth is a historical body, the history of the earth is very long, and the earth is dynamic (development of plate tectonics). He has run the course six times, collecting data on student learning, and is currently documenting the process and learning outcomes in a book. **We propose** to research the history of the concepts of earthquake magnitude and intensity to understand the context of their development through time and to document this development in a historical case study (or multiple case studies). Our **intended outcome** is to create a historical case study that will highlight the development and especially the meanings of earthquake magnitude and intensity for educational use, such as in formal education environments (schools) or other informal education locations, such as museums, libraries, and parks.

3. Socio-Cultural Approach

Many other regions of the world experience high occurrences of earthquakes and have developed their own tactics and strategies for lowering the risk to property and life, to include the implementation of EEW (Figure 2 from *McBride et al.,* 2021). As EEW grows internationally, colleagues in Mexico and Latin America have also expressed misconceptions around earthquake magnitude and intensity (*D. Sumy*, pers. comm., 2021). Understanding how these other regions have approached the problem, and the efficacy of those approaches would be invaluable to formulating our own processes here in Canada. For instance, Japan has implemented their own EEWS based on an algorithm called PLUM (Propagation of Local Undamped Motion; *Kilb et al.*, 2021) that places emphasis on earthquake intensity over magnitude, and is currently under consideration for the USGS ShakeAlert project. Japan has taken a multi-faceted approach to educating their public to know what to do in the event of an earthquake, and their education places much more emphasis on earthquake intensity instead of magnitude (Aoi et al., 2020). This is unlike North America, which has the emphasis reversed. We **propose** to investigate areas using earthquake early warning systems and see how they present information about earthquakes and the alerts from their systems. We will inventory common approaches to teaching the key concepts of magnitude and intensity over time and assess what is known about the merit of each of these approaches within each culture. In this case merit likely includes alignment with scientific understanding of ideas, as well as educational best practices. We can then start to develop a series of best practices for addressing the problems encountered by the USGS with their ShakeAlert system and be able to mitigate such issues with proper education strategies in the public, schools, universities, and First Nations populations. Our **intended outcome** is to create a series of evidence-based practices that can be implemented in direct communications with the public, as well as shaping interventions in school and university-based curriculum that will address the notions of earthquake intensity and magnitude and how to react in the case of an earthquake early warning.

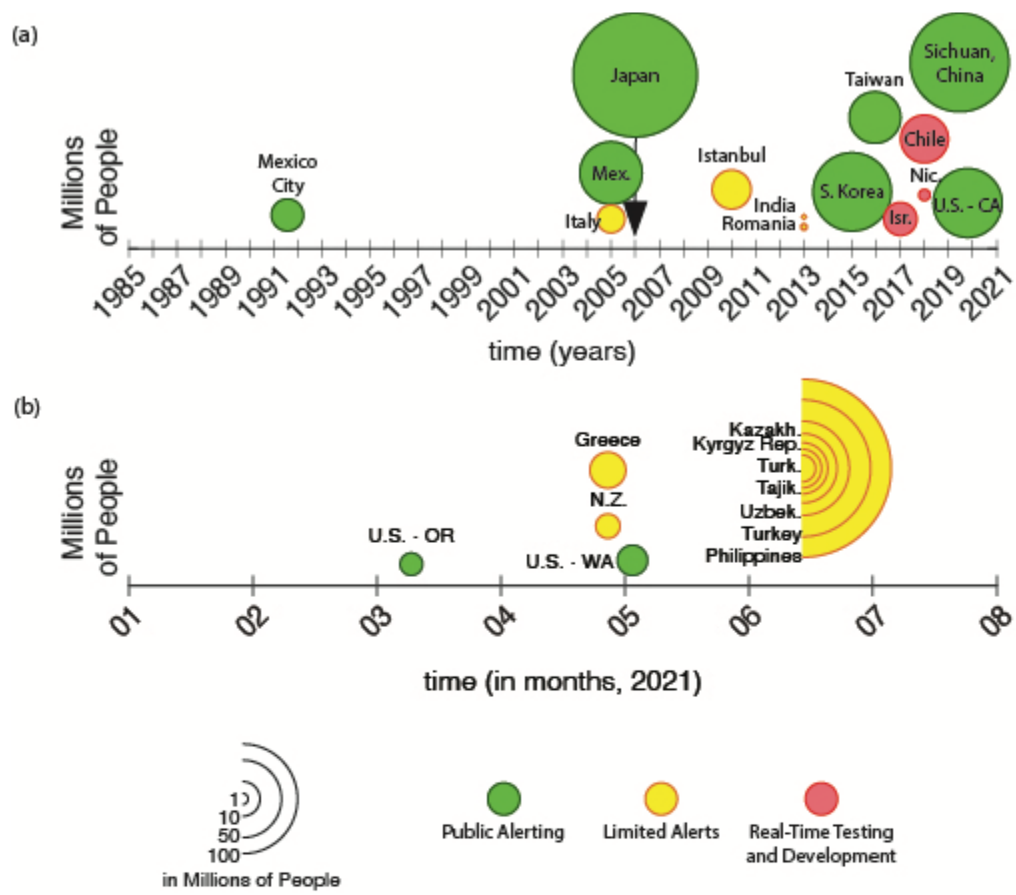

Figure 2. The timeline of earthquake early warning roll-out around the world, (a) for 1985 through 2020 and (b) for 2021, scaled by the millions of people to be potentially notified with an alert. The

colors represent the various stages of earthquake early warning roll-out: public alerting (green), limited alerts delivered to technical users and/or pilot testers (yellow), and EEW testing and development (red), as defined in the legend. In 2017 and 2018, Israel (Isr.) and Nicaragua (Nic.) began real-time testing and development of their EEW systems, respectively. In (b), the limited public alerting (yellow) is delivered by Google Android only; thus, only people with an Android operating system phone can receive alerts. Figure from *McBride et al.* [2021].

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