THE INFLUENCE OF KNOWLEDGE ACQUISITION ON ATTITUDES TOWARDS RADIATION AND NUCLEAR TECHNOLOGIES AMONG NON-EXPERTS IN SASKATCHEWAN

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By
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SUPERVISORY AND EXAMINING COMMITTEE

Shawn Riley Robinson, candidate for the degree of Master of Public Policy, has presented a thesis titled, *The Influence of Knowledge Acquisition on Attitudes Towards Radiation and Nuclear Technologies Among Non-Experts in Saskatchewan* in an oral examination held on February 13, 2020. The following committee members have found the thesis acceptable in form and content, and that the candidate demonstrated satisfactory knowledge of the subject material.

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ABSTRACT

The information deficit model attempts to explain the difference in attitudes that are held between experts and the lay public towards the use and application of matters of science. This model suggests that a paucity of scientific understanding and knowledge can lead to skepticism regarding a particular matter of science, and rejection of its use in a societal context. For example, in the case of radiation, non-experts view nuclear power plants and nuclear waste as riskier than do scientific experts on radiation, while the opposite is true when radiation is being applied in a medical context. The information deficit model is critiqued by opponents who point out that by focusing on the difference in knowledge between experts and non-experts, other elements that shape attitudes are not considered (such as ideology, political affiliations, religion, and value-based identities). Direct testing of the information deficit model through application of an experimental approach is a gap in the existing literature.

This research addressed this gap by performing a test of the information deficit model used a controlled experimental method. Random digit dialing was used to query 500 residents of Saskatchewan on their attitudes and knowledge about radiation. Subsequently, 80 of those individuals were separated into an education group (n = 43) and control group (n = 37). The education group received an education booklet and viewed educational videos on radiation. Both groups were then queried again on their attitudes and knowledge on radiation using the same questionnaire.

A regression model of the responses from all 500 participants indicated a significant relationship between knowledge about radiation and attitudes towards radiation. Within the experimental treatment, the education group saw a significant increase in radiation knowledge along with an increase in overall radiation attitudes and specific radiation attitudes pertaining to nuclear power and societal approaches to radiation. This resulted in a lower risk assessment for some aspects of radiation among
the education group, including nuclear power plants. When medical radiation was considered, the education group had a significantly higher attitude following the educational intervention when initial attitudes were low, and a significantly lower post-intervention attitude when the initial attitude was the highest possible score. In a similar vein, CT scans were rated as riskier by education participants than the control group following the intervention. Pearson’s correlation indicated that, within the education group, the change in knowledge scores was correlated with a change in radiation attitude scores, with the exception of medical radiation.

While not precluding the role of other factors, the results here indicate a role for knowledge in the formation of attitudes towards radiation. This understanding allows for a more robust prediction towards how the general public may participate in public policy processes, such as deliberative engagement.
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DEDICATION

For Emilie. Thank you for your patience and your endless, unwavering support.
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.3.1</td>
<td>Internal Consistency and Reliability</td>
<td>21</td>
</tr>
<tr>
<td>2.3.2</td>
<td>Descriptive Statistics</td>
<td>21</td>
</tr>
<tr>
<td>2.3.3</td>
<td>Relationship Between Knowledge and Attitudes using Multiple Linear Regression</td>
<td>24</td>
</tr>
<tr>
<td>2.3.3.1</td>
<td>Overall Radiation Attitudes</td>
<td>24</td>
</tr>
<tr>
<td>2.3.3.2</td>
<td>Nuclear Power Radiation Attitudes</td>
<td>26</td>
</tr>
<tr>
<td>2.3.3.3</td>
<td>Medical Radiation Attitudes</td>
<td>28</td>
</tr>
<tr>
<td>2.3.3.4</td>
<td>Societal Approach to Radiation Attitudes</td>
<td>28</td>
</tr>
<tr>
<td>2.4</td>
<td>Discussion</td>
<td>31</td>
</tr>
<tr>
<td>2.5</td>
<td>Concluding Remarks</td>
<td>36</td>
</tr>
</tbody>
</table>

**CHAPTER THREE: EFFECTS OF EDUCATION ON RADIATION ATTITUDES IN A CONTROLLED EXPERIMENT**

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Introduction</td>
<td>37</td>
</tr>
<tr>
<td>3.2</td>
<td>Methods</td>
<td>37</td>
</tr>
<tr>
<td>3.2.1</td>
<td>Participant Pool</td>
<td>37</td>
</tr>
<tr>
<td>3.2.2</td>
<td>Participant Recruitment and Treatment Groups</td>
<td>38</td>
</tr>
<tr>
<td>3.2.3</td>
<td>Education Materials</td>
<td>39</td>
</tr>
<tr>
<td>3.2.3.1</td>
<td>Chapter One – Introduction to Radiation</td>
<td>40</td>
</tr>
<tr>
<td>3.2.3.2</td>
<td>Chapter Two – Radiation’s Impact on the Human Body</td>
<td>40</td>
</tr>
<tr>
<td>3.2.3.3</td>
<td>Chapter Three – Natural Sources of Radiation</td>
<td>41</td>
</tr>
<tr>
<td>3.2.3.4</td>
<td>Chapter Four – Human-Controlled Sources of Radiation</td>
<td>41</td>
</tr>
<tr>
<td>3.2.3.5</td>
<td>Chapter Five – Exposure Comparison</td>
<td>42</td>
</tr>
<tr>
<td>3.2.3.6</td>
<td>Chapter Six – Other Uses for Radioactive Materials</td>
<td>42</td>
</tr>
<tr>
<td>3.2.3.7</td>
<td>Accompanying Education Videos</td>
<td>42</td>
</tr>
<tr>
<td>3.2.4</td>
<td>Second Application of the Radiation Questionnaire</td>
<td>43</td>
</tr>
<tr>
<td>3.2.5</td>
<td>Data Analysis</td>
<td>43</td>
</tr>
<tr>
<td>3.3</td>
<td>Results</td>
<td>45</td>
</tr>
</tbody>
</table>
3.3.1 Demographic Comparison of Control and Education Groups ........45
3.3.2 Impact of Education on Knowledge Scores ..........................47
   3.3.2.1 Descriptive Statistics – Knowledge .........................47
   3.3.2.2 Shapiro-Wilk Test for Normality – Knowledge ............47
   3.3.2.3 Mixed Model ANOVA – Knowledge ..........................49
   3.3.2.4 T-tests – Knowledge ..............................................49
   3.3.2.5 Mann Whitney U Test – Knowledge ..........................51
   3.3.2.6 Gain Scores – Knowledge .........................................51
   3.3.2.7 ANCOVA Analysis with Johnson-Neyman Procedure – Knowledge .................................................................54
   3.3.2.8 Summary – Influence of Educational Intervention on Knowledge Scores ...............................................................54
3.3.3 Impact of Education on Overall Radiation Attitudes ..............56
   3.3.3.1 Descriptive Statistics – Overall Radiation Attitudes ....56
   3.3.3.2 Shapiro-Wilk Test for Normality – Overall Radiation Attitude .................................................................56
   3.3.3.3 Mixed Model ANOVA – Overall Radiation Attitude ....58
   3.3.3.4 T-Test – Overall Radiation Attitude ..........................58
   3.3.3.5 Mann Whitney U Test – Overall Radiation Attitude ....58
   3.3.3.6 Gain Scores – Overall Radiation Attitude .....................61
   3.3.3.7 ANCOVA Analysis with Johnson-Neyman Procedure – Overall Radiation Attitude ..................................................61
   3.3.3.8 Overall Radiation Attitude Summary ..........................64
3.3.4 Impact of Education on Nuclear Power Attitudes ..................64
   3.3.4.1 Descriptive Statistics – Nuclear Power Attitude ..............64
   3.3.4.2 Shapiro-Wilk Test for Normality – Nuclear Power Attitude ..............................................................................65
3.3.4.3 Mixed Model ANOVA – Nuclear Power Attitude ..........65
3.3.4.4 T-test – Nuclear Power Attitude.............................................65
3.3.4.5 Mann Whitney U Test – Nuclear Power Attitude..........68
3.3.4.6 Gain Score – Nuclear Power Attitude..........................68
3.3.4.7 ANCOVA with Johnson-Neyman Procedure – Nuclear Power Attitude .................................................................68
3.3.4.8 Nuclear Power Attitude Summary.................................72

3.3.5 Impact of Education on Medical Radiation Attitudes ..........72
3.3.5.1 Descriptive Statistics – Medical Radiation Attitude.........72
3.3.5.2 Shapiro-Wilk Test for Normality – Medical Radiation Attitude...........................................................................73
3.3.5.3 Mixed Model ANOVA – Medical Radiation Attitude.......73
3.3.5.4 T-Test – Medical Radiation Attitude.................................73
3.3.5.5 Mann Whitney U Test – Medical Radiation Attitude .......76
3.3.5.6 Gain Score – Medical Radiation Attitude......................76
3.3.5.7 ANCOVA with Johnson-Neyman Procedure – Medical Radiation Attitude .................................................................76
3.3.5.8 Medical Radiation Attitude Summary ................................79

3.3.6 Impact of Education on Societal Approach to Radiation Attitudes....79
3.3.6.1 Descriptive Statistics – Societal Approach to Radiation Attitude...........................................................................79
3.3.6.2 Shapiro-Wilk Test for Normality – Societal Approach to Radiation Attitude...........................................................................81
3.3.6.3 Mixed Model ANOVA – Societal Approach to Radiation Attitude...........................................................................81
3.3.6.4 T-Test – Societal Approach to Radiation Attitude...........81
3.3.6.5 Mann Whitney U Test – Societal Approach to Radiation Attitude................................................................. 84
3.3.6.6 Gain Score – Societal Approach to Radiation Attitude …..84
3.3.6.7 ANCOVA with Johnson-Neyman Procedure – Societal Approach to Radiation Attitude......................................................... 84
3.3.6.8 Societal Approach to Radiation Attitude Summary.................87
3.3.7 Summary Table of Knowledge and Attitude Change...................89
3.3.8 Influence of Knowledge Gain on Radiation Attitude Change........ 91
3.3.9 Risk Rating of Sources of Radiation...........................................91
3.3.10 Assessment of Use of Radiation in Particular Contexts ..........98

3.4 Discussion....................................................................................................................105

CHAPTER FOUR: CONCLUDING THOUGHTS AND POLICY IMPLICATIONS ..........109

LITERATURE CITED.................................................................................................................115

APPENDIX A – INITIAL QUESTIONNAIRE ............................................................ 122
APPENDIX B – RADIATION EDUCATION BOOKLET ....................................................... 140
APPENDIX C – RADIATION EDUCATION VIDEO SLIDES AND SCRIPT .......... 171
APPENDIX D – EXIT QUESTIONNAIRE (CONTROL GROUP) ......................... 225
APPENDIX E – EXIT QUESTIONNAIRE (EDUCATION GROUP) ...................... 238
APPENDIX F – PARTICIPANT DEBRIEF SCRIPT...................................................... 239
APPENDIX H – RESEARCH ETHICS APPROVAL .................................................. 240
LIST OF TABLES

Table 1: Cronbach’s alpha for radiation attitudes and knowledge ..................................22

Table 2: Participant demographics compared to Saskatchewan........................................46

Table 3: Summary of Knowledge and Attitude Change Following Education Intervention – Knowledge, Overall Radiation Attitudes, and Nuclear Power Radiation Attitudes ........89

Table 4: Summary of Knowledge and Attitude Change Following Education Intervention – Medical Radiation Attitudes and Societal Approach to Radiation Attitudes ..................90

Table 5: Pearson correlation matrix of change in radiation attitudes and change in knowledge scores following education intervention................................................... 92
LIST OF FIGURES

Figure 1: Overall Radiation Attitudes Regression Model ..................................................25
Figure 2: Nuclear Power Radiation Attitudes Regression Model ......................................27
Figure 3: Medical Radiation Attitudes Regression Model ...............................................29
Figure 4: Societal Approach to Radiation Regression Model ...........................................30
Figure 5: Distribution of Knowledge Scores Before and After Educational Intervention.48
Figure 6: Estimated Marginal means of Knowledge Scores ............................................50
Figure 7: Mann Whitney U Test Distributions for Knowledge Scores Between Control and Education Groups .................................................................................................52
Figure 8: Mann Whitney U Test Distributions for Knowledge Scores Within Control and Education Groups ...........................................................................................................53
Figure 9: Johnson-Neyman Analysis for Knowledge Scores .............................................55
Figure 10: Distribution of Overall Radiation Attitude Scores Before and After Educational Intervention .......................................................................................................................57
Figure 11: Estimated Marginal Means of Overall Radiation Attitude Scores .....................59
Figure 12: Mann Whitney U Test Distributions for Overall Radiation Attitude Scores Between Control and Education Groups ...............................................................60
Figure 13: Mann Whitney U Test distributions for Overall Radiation Attitude Scores Within Control and Education Groups ...................................................................................62
Figure 14: Johnson-Neyman Analysis for Overall Radiation Attitude Scores ....................63
Figure 15: Distribution of Nuclear Power Attitude Scores Before and After Educational Intervention ..........................................................................................................................66
Figure 16: Estimated marginal Means of Nuclear Power Attitude Scores .........................67
Figure 17: Mann Whitney U Test Distributions for Nuclear Power Attitude Scores Between Control and Education Groups ..................................................................................69
Figure 18: Mann Whitney U Test Distributions for Nuclear Power Attitude Scores Within Control and Education Groups ..........................................................................................70
Figure 19: Johnson-Neyman Analysis for Nuclear Power Attitude Scores .......................71
Figure 20: Distribution of Medical Radiation Attitude Scores Before and After Educational Intervention

Figure 21: Estimated Marginal Means of Medical Radiation Attitude Scores

Figure 22: Mann Whitney U Test Distributions for Medical Radiation Attitude Scores Between Control and Education Groups

Figure 23: Mann Whitney U Test Distributions for Medical Radiation Attitude Scores Within Control and Education Groups

Figure 24: Johnson-Neyman Analysis for Medical Radiation Attitude Scores

Figure 25: Distribution of Societal Approach to Radiation Attitude Scores Before and After Educational Intervention

Figure 26: Estimated Marginal Means of Societal Approach to Radiation Attitude Scores

Figure 27: Mann Whitney U test Distributions for Societal Approach to Radiation Attitude Scores Between Control and Education Groups

Figure 28: Mann Whitney U Test Distributions for Societal Approach to Radiation Attitude Scores Within Control and Education Groups

Figure 29: Johnson-Neyman Analysis for Societal Approach to Radiation Attitude Scores

Figure 30: Radiation Source Risk Assessment Control Group

Figure 31: Radiation Source Risk Assessment Education Group

Figure 32: Radiation Source Risk Assessment Control vs. Education Pre-Intervention

Figure 33: Radiation Source Risk Assessment Control vs. Education Post-Intervention

Figure 34: Use of Radiation Control Group

Figure 35: Use of Radiation Education Group

Figure 36: Use of Radiation Control vs. Education Pre-Intervention

Figure 37: Use of Radiation Control vs. Education Post-Intervention
CHAPTER ONE: INTRODUCTION

1.1 Deliberative Democracy and Science Policy

The role of the public in decision making processes is one that continues to evolve. Recent trends in public engagement thinking have moved towards increased public participation in decision making processes. One such application of public engagement can occur through ‘deliberative democracy’. In deliberative democracy scenarios, members of the public are invited to weigh information and participate in a dialogue on particular policy issues or problems.

Deliberative democracy has been proposed as a mechanism to address low citizen participation issues in democratic processes (Nabatchi 2010). Deliberative approaches, such as citizen juries, deliberative polling, consensus conferences, and stakeholder workshops, extend the ability of the public to go beyond merely being informed of decisions and outcomes. Instead, members of the public can become active participants in the policy process (Marris and Rose 2010). During a deliberative democratic process, participants are able to consider information on a subject within the context of their own values (Dietz 2013). These processes are not a one-way conversation of policy makers or experts providing their opinions for the participating public. Rather, deliberative democracy includes elements of listening, reflection, and mutual, two-way communication (Dryzek et al. 2019). Through these processes, participants are provided the opportunity to consider different arguments and provide conclusions and recommendations to policy makers (Wouters et al. 2019). Such a process can enhance both the quality and legitimacy of decision making (Dietz, 2013; Irwin, 2006; Goodfellow et al. 2011).

The implementation of deliberative democracy can be extended to policy decision making within the purview of science and technology (Joss 1999; Durant 1999; Dietz 2013; Marris and Rose 2010). Science and technology policy provides an
interesting subset of decision making, in which subcategories of people can be clearly
defined. Those who have studied intensely within an area of science and technology are
considered ‘experts’, who have a more advanced understanding of the issue at hand
than would the general lay public who have not received the requisite training. Science
and technology decisions making has traditionally been limited to the realm of these
subject matter experts, along with policy analysts and decision makers. However, a
deliberative democratic process can extend this list of stakeholders to a larger number
of participants, including non-governmental organizations, interest groups, local
communities, and individual citizens (Joss 1999).

Inclusion of more such ‘publics’ can be used to address a power imbalance
between experts and non-experts, and provide recognition that the scientific expertise
brought forward by experts need not be the only aspect considered when weighing
science and technology policy decisions. Increased involvement of the public allows for
local knowledge, which may not be held by experts unfamiliar with the local
circumstances and nuance, to contribute to the policy discourse (Yearly, 2000; Wynne,
1991). It is also a transition away from blind trust in scientists and policy makers to one
of public discourse and engagement (Irwin, 2006). Deliberative decision making has
been attempted or proposed for several areas of science and technology policy,
including genetically modified foods (Nep and O’Doherty, 2012), nanotechnology (Jones
et al., 2014; Russell, 2013), genomics (Sturgis et al. 2010), energy options (Hall et al.,
2011), and CRISPR gene editing (Jasanoff et al., 2015).

The ability for non-experts to reasonably participate in decision making
processes about science and technology can be called to question in light of the
scientific knowledge gap between experts and the lay public. The existence of this
knowledge gap in and of itself is self-evident. The general public cannot be expected to
have the same level of working knowledge about a science or technology topic when
these areas tend to be involved, complex, and requiring many years of focused
education to fully understand. However, the relevance of this knowledge gap when considering science and technology policy is an area open for debate. It is questionable whether the general, non-expert public has the capacity to participate in a sensible fashion in science and technology if they lack certain scientific knowledge (Irwin, 2006), as is how knowledge may be influencing attitude formation and subsequent decision making.

1.2 Attitude and Attitude Change

Prior to a discussion on how attitudes are being formed, maintained, or modified within the specific realm of science policy, it is necessary to establish what is meant by ‘attitudes’ and for a brief discussion on current theories on attitude formation and change.

Attitudes are, in their most simple explanation, anything that a person may hold in the mind (Bohner and Dickel, 2011). These thoughts may be about an object, person, or idea and generally contain some aspect of evaluation – for or against, favour or disfavor (Albarracin and Shavitt, 2018). Attitudes are of interest not only in of themselves, but in the role that attitudes can play in guiding behavior (Bohner and Dickel, 2011; Albarracin and Shavitt, 2018). A study of attitude change can therefore be useful as a means to predict subsequent changes in actions.

The precise neurocognitive mechanisms in which attitudes are formed are uncertain. Multiple models exist, which suggest that attitudes are stable constructs formed in memory and subsequently recalled when necessary, temporary constructs based on in-the-moment information, or a hybrid mechanism of these two approaches. It has been proposed that the hybrid model best accounts for attitude stability as well as attitude change (Bohner and Dickell, 2011; Albarracin and Shavitt, 2018).

The underlying neurocognitive mechanisms underlying attitude formation and change is beyond the scope of this thesis. However, the body of attitude research provides the basis upon which a conversation on attitudes and attitude change in
regards to science policy can be held. For the purposes of this thesis, the definition of ‘attitude’ will be no more specific than this general definition; it will be used to reflect participants’ thoughts towards abstract ideas. Through use of survey questions, these attitudes can be explicitly measured, and by repeating the measurement changes in attitude can be assessed (Albarracin and Shavitt, 2018).

1.3 The Information Deficit Model

The information deficit model is an attempt to explain the apparent differences between the lay public’s and experts’ attitudes on matters pertaining to science. It was first developed in the 1980’s by those studying science communication (Dickson, 2005). The underpinnings of the deficit model lie in the naturally inherent differences in the levels of expertise between experts and non-experts in areas of science and technology.

The deficit model proposes that a lack of scientific understanding and awareness leads to skepticism, doubt, or even rejection of a particular technology or technological application (Sturgis and Allum, 2004). A key concept is how expert and lay people are performing ‘risk’ assessments of different technologies. Risk can be defined in several ways. Slovic and Peters (2006) suggest that risk can be constructed in two different manners: once as feelings using instinctive reactions to dangers and again as analysis using logic reason and deliberation. Sandman (1987) purports that risk is comprised of two elements, ‘hazard’ (meaning the death rate; a technical assessment) and ‘outrage’ (which includes several elements such as voluntariness, control, fairness, and dread; a cultural assessment). Experts tend to use the former method of assessing risks, while the lay public uses the latter (Sandman, 1987; Slovic 1987; Engdahl and Lidskog, 2014). The information deficit model would suggest the cause of this discrepancy is a difference in knowledge; non-experts are purported to make different risk assessment of technological applications simply because they do not have the same level of knowledge as experts (Hansen et al, 2003). Subsequently,
engagement efforts on the part of experts with the general public become focused on a one-way communication in an effort to increase the understanding of the ‘ignorant’ public on a particular topic and to overcoming any negative sentiments that may have originally existed (Nisbet and Scheufele, 2009; Sulovský, 2016).

The rigor of the information deficit model cannot be questioned on the basis of the general public’s working knowledge of science and technology. Regardless of the interpretation of the impact of the fact, there is a general lack of scientific awareness among the lay public. For example, in a report by the Council of Canadian Academies, Canada placed first of 35 countries surveyed for scientific literacy, yet only 42 percent of Canadian were deemed to have a basic level of scientific understanding (Council of Canadian Academies, 2014). The gap in textbook scientific knowledge between experts and non-experts is demonstrable, but the role of that knowledge gap in determining attitudes and policy preferences is contentious.

Critics of the deficit model point to its failure to consider the context in which knowledge acquisition (or lack thereof) is occurring. They portend that the deficit model fails in its assumption that the ‘public’ is a homogenous pool in which facts are self-apparent and self-defending, and are interpreted by everyone in the same manner (Nisbet and Scheufele, 2009; Engdahl and Lidskog, 2014). The deficit model, by suggesting the underlying difference in opinion between experts and non-experts is rooted entirely within a difference in knowledge, does not allow for consideration of other influences that shape attitudes, including, for example, ideology, partisanship and political affiliations, religious identity, basic values, general risk tolerance, beliefs, emotions, and biases (Hansen et al., 2003; Petty and Brinol, 2010; Nisbet and
Scheufele, 2009; Ho et al, 2010). Furthermore, information assessment and assimilation occur in the context of social relationships, societal or concerns, and pre-established and value-based identities. Some authors have written off the information model as “dead”, and should be replaced by a “contextual” model that does not rely solely upon information sharing but includes cultural context in the form of frames to create effective messaging on matters of science (McDivitt, 2016).

A transition away from the deficit model lends itself to different approaches to science communication and engagement. It has been suggested that more effort is needed on the part of scientific experts to be more open to a conversation on first principles, where a discussion can occur on what the most important concerns actually are, rather than a focus on risk assessments (Hansen et al., 2003; Wynne, 2008). This would require a shift away from a scientific education attempt to span the knowledge gap between experts and non-experts, and move towards dialogue that can consider a variety of influences on attitude formation and policy decision making.

Despite the clear opposition to the information deficit model, the veracity of the model, and the extent to which knowledge influences attitude formation, remains an open question. Some research indicates that knowledge does influence attitude formation. A meta-analysis of 193 surveys on the public understanding of science and scientific attitudes found a consistent positive relationship between the two metrics (Allum et al., 2008; however it should be noted that other authors contextualized this result as knowledge representing only a small portion of the variables informing how non-experts develop attitudes towards controversial areas of science [Nisbet and Scheufele, 2009]). Recent research has indicated that, when knowledge is properly assessed objectively rather than through self-assessment, the deficit model provides a reasonable explanation for the apparent difference between expert and non-expert attitudes (Stoutenborough and Vedlitz, 2014; Stoutenborough and Vedlitz, 2016; Guy et
al., 2014). These results suggest that further testing of the information deficit model, particularly through a controlled experimental design, would prove valuable in assessing the role that information plays in the formation of attitudes.

1.4 The Information Deficit Model as it Applies to Radiation

Radiation attitudes present an intriguing case study to explore the veracity of the information deficit model. As with many other instances of science and technology, the general public views radiological risks differently than do radiation experts. Non-experts tend to view nuclear power facilities and nuclear waste as riskier than do experts. Conversely, the lay public assesses medical procedures which use radiation (such as x-rays) and naturally occurring sources of radiation (such as radon gas) less risky than do experts (Slovic, 2012; Perko, 2014; Sandman et al., 1987; Stoutenborough et al., 2013).

Lay public concerns surrounding nuclear power typically reside around association with nuclear weapons, the potential for disasters, and the movement and storage of nuclear waste (Yim and Vaganov, 2003; McBeth and Oakes, 1996; Slovic, 1987). From a risk analysis perspective, nuclear power and nuclear waste is considered to be highly dreaded, highly unknown, and involuntary, contributing towards to a higher risk assessment by radiation non-experts (Slovic, 2012; Goodfellow et al., 2011; Cha, 2004; Slovic, 1987). Conversely, the public is able to observe the direct benefit of medical radiation and has high trust in the practitioners of the radiation exposure (e.g. trained physicians), which contributes to a lower risk assessment (Slovic, 2012).

The disparity between the general public and experts on the risk associated with radiation, and the differential risk assessment made towards several applications of radiation, makes attitudes towards radiation an ideal test case for assessing the role that knowledge plays in influencing the development of attitudes in the general population.
1.5 The Context of Radiation in Saskatchewan

Saskatchewan is a significant contributor to the global uranium industry. It is the only uranium producing province in Canada, and accounts for 16 per cent of the world’s uranium supply (Saskatchewan Mining Association, 2019a). The uranium sector employs 1,844 employees and contractors, and is a significant employer of residents in the relatively remote and sparsely populated Northern Saskatchewan (Saskatchewan Mining Association, 2019b). In 2017, taxes and royalties paid to the Government of Saskatchewan from the uranium sector totalled $94.5 million (Saskatchewan Mining Association, n.d.). However, mine closures and layoffs have recently occurred due to depressed uranium spot prices.

Despite the vast uranium reserves and economic benefits that would occur from an expanded uranium mining sector, Saskatchewan has to date failed to pursue extended exploitation of the uranium value chain, including its use in nuclear power facilities. The possibility of nuclear power in the province has been explored previously through feasibility studies conducted as early and 1972, and more recently by Bruce Power in 2008 (Hurlbert et al., 2011). The Government of Saskatchewan conducted a panel investigation into the possibility of expanding upon the uranium value chain in Saskatchewan, along with a subsequent public consultation. This process indicated public opposition to the potential development of nuclear power facilities in Saskatchewan (Hurlbert et al., 2011; Perrins, 2009). Organizations opposed to nuclear power development in the province noted risks including construction costs, the production of radioactive waste, and connections to nuclear weapons (Saskatchewan Environmental Society, 2009). In contrast to the results found in the Perrins Future of Uranium Public Consultation Process report, other public opinion polls on the issue suggested public support for nuclear power could be as high as 66 percent (Fried et al., 2014).
The potential for nuclear power development in Saskatchewan is likely to return as a policy debate. In *Prairie Resilience: A Made in Saskatchewan Climate Change Strategy*, the Government of Saskatchewan committed to reducing its greenhouse gas emissions associated with electricity production by 40 percent below 2005 levels by 2030 (Government of Saskatchewan, 2017). Regulations to that effect, *The Management and Reduction of Greenhouse Gas Emissions (General and Electricity Producer) Regulations*, were introduced on January 1, 2018 (Government of Saskatchewan, 2018). In order to reach those targets, SaskPower, the provincial crown corporation governing electricity production and distribution, will need to adjust its electricity generation mixture that is currently heavily reliant on coal and natural gas (SaskPower, 2019). In recent media correspondence, Scott Moe, the premier of Saskatchewan, signalled that the province is exploring the potential for small modular nuclear reactors to be installed in order to help Saskatchewan meet its reduction targets (CBC, 2019). On December 1, 2019, the Government of Saskatchewan, Ontario, and New Brunswick signed a Memorandum of Understanding towards the development and implementation of small modular reactors (Government of Saskatchewan, 2019).

The hesitancy to pursue nuclear development in Saskatchewan historically may be due to a concern regarding public backlash. The report from Perrins (2009) failed to provide confidence to the government of the day that initiatives to expand upon the nuclear value chain would be well received by members of the Saskatchewan public, despite the benefits that could bring to the Northern Saskatchewan economy. Understanding the construct of radiation attitude formation among members of the public, and whether those attitudes are in any way shaped by a general knowledge deficit on the topic of radiation, would provide illuminating for should any attempt to expand the nuclear sector be made in the province.
1.6 Research Question - Testing the Deficit Model through a Controlled Experiment

While the validity of the deficit model and the influence of knowledge on attitude formation is debateable, a potential solution to bridging the gap between experts and non-experts is an application of deliberative democracy to science (Nisbet and Scheufele, 2009; Suldovsky, 2016). While an increased role for the public is a worthy pursuit regardless of the truth of the deficit model, concern does exist of the ability of the lay public to adequately participate in a democratic decision making process regarding science or technology if there is an informational deficit on the issue (Stoutenborough and Vedlitz, 2016; Irwin, 2006). There remains an opportunity, then, to further our understanding for how information acquisition can be expected to influence attitude formation in science and technology and how the lay public can be expected to receive, assess, and apply new information about science and technology.

The aim of this study is to test one of the core tenets of the deficit model by providing educational materials on radiation to the lay public who previously would not have been expected to have a significant understanding of radiation’s basic science or its application. The deficit model would predict that providing this information to participants will result in their attitudes becoming more aligned with radiation experts. That is, attitudes towards application of radiation in the nuclear power sector would be predicted to start low and become higher following the education, while attitudes regarding medical radiation would be anticipated to begin high and lower after the intervention. If education on radiation does not have a significant influence on attitude formation, contrary to the predictions of the deficit model, attitudes would be predicted to stay consistent before and after the educational intervention.

An experimental design was used to test the relationship between radiation knowledge and attitudes. Random digit dialing of residents of Saskatchewan was
completed to form an initial pool of participants who were queried on their attitudes and knowledge about radiation. Continuing participants were then separated into an education treatment group which received an education booklet and viewed educational videos on radiation, and a control treatment group which did not receive the educational intervention. Both groups were then again be queried on their radiation knowledge and attitudes (more details of the methodology applied in this work are provided in Chapters 2 and 3).

Implementation of a controlled experiment study allowed for statistical assessment of the influence of the education materials on subsequent knowledge and attitude scores. Similar approaches in the literature are relatively scant. MacGregor (2002) made use of an educational intervention to observe the influence of a radiation educational intervention on radiation attitudes, but failed to include a control group and limited his participant pool to university students. Showers and Shrigley (1995) used a quasi-experimental approach to demonstrate that nuclear knowledge and attitudes could be changed independently, however again a control group was absent and the participant pool was limited to high school students. While not specific to radiation attitudes, Sturgis et al. (2010) failed to find a significant change in attitudes on genomic science using a controlled education approach, while Sanderson et al. (2005) used a similar methodology to test the influence of an informational pamphlet on public attitudes towards genetic testing, finding that the education group had an increase in understanding and a better attitude but with no demonstrable link between the two. Chandra (2014) used a systems dynamics methodology to construct a model of components which interact to inform attitudes towards radiation. Among several other factors (including perceived personal benefit and risk, trust in nuclear enterprise, media commentary and credibility, and weapons associated), level of education and familiarity with nuclear science and technology were indicated to inform radiation attitudes. While
Chandra used interviews to test the veracity of his model, the research did not tests its components using a controlled experimental design.

It has been noted elsewhere that the influence of education on radiation risk perceptions and attitudes would benefit from future study (Slovic, 2012), while Sturgis et al. (2010) suggested that the link between scientific knowledge and attitudes needs to be assessed and observed within each particular context. This thesis provides valuable information about the role that the information deficit model may play in attitude formation by making use of a controlled experimental approach. It also provides situation-specific context on the degree to which radiation knowledge and radiation attitudes are linked in the lay public, demonstrates whether a brief educational intervention (such as what may be used during a deliberative democratic process) is a suitable mechanism to increase citizen knowledge on a complex topic, and helps to predict whether that education alone can be expected to change attitudes.
2.1 Introduction

Previous studies have made use of regression modeling to examine the relationship between knowledge and attitudes (see Chapter 1). Regression modelling allows for analysis following the single application of a survey to a participant group by including scores on a knowledge battery among a series of other independent variables to predict the scores on a dependent variable (in this circumstance, radiation attitude scores). Currently, a regression model does not exist that predicts the relationship between radiation knowledge and attitudes that is specific to Saskatchewan. Such a model would extend existing research into the Saskatchewan context, and provide valuable information on the potential relationship between radiation knowledge and attitudes. It would also provide a predictive framework as to whether education on radiation could be expected to subsequently shift radiation attitudes.

2.2 Methods

2.2.1 Survey Design

A telephone questionnaire was created to obtain the necessary data to create a linear regression model on the extent to which knowledge influences radiation attitudes in Saskatchewan (see Appendix A).

Participants’ knowledge on radiation was assessed through a series of 24 questions. The knowledge questions were both adapted from previous work exploring radiation attitudes (Bourassa et al., 2016; Evans et al., 2015; MacGregor, 2002; Perko et al., 2012) and newly developed questions for this study. The knowledge battery consisted of 16 true or false questions with four options (“true”, “false”, “unsure”, and “choose not to answer”; questions 22 – 37 of the survey); five questions about whether
certain medical procedures use radiation, with four options (“yes”, “no”, “unsure’, “choose not to answer”; questions 38 – 42); and three questions where the participant was asked to select which of two scenarios would expose a person to more radiation, with four options (scenario A, scenario B, “unsure”, “choose not to answer”; questions 43 – 45).

The knowledge questions were selected on the basis that they covered several varied aspects of radiation. These included the nature and science of radiation, where radiation occurs (natural and human-controlled sources), application of radiation in nuclear power plants and associated hazards, the use of radiation in medicine, and the relative amount of radiation that a person may be exposed to under certain conditions. This allowed for a robust quantification of participants’ overall knowledge on radiation, rather than basing a knowledge assessment on a small number of questions representing a narrow scope of radiation. The questions were written in a manner to which a correct answer could be provided with certainty should the participant have the requisite knowledge on the topic.

Unintended ambiguity may have been introduced in the knowledge questions regarding use of radiation in medical procedures (questions 38 to 42 in the survey). The questions were framed as to whether the procedures used radiation, without clarification as to whether that radiation was ionizing radiation. Some procedures use ionizing radiation (e.g. x-rays and CT scans), while others use non-ionizing radiation (e.g. MRIs). The difference between ionizing and non-ionizing radiation in medical procedures is important given the potential negative health implications from ionizing radiation, while non-ionizing radiation is considered harmless. Participants with sufficient knowledge to differentiate between ionizing and non-ionizing radiation within medical procedures may therefore have been uncertain as to the intention of the question. For four of the listed procedures the difference was without consequence, as the procedure either was
absent of radiation entirely or used ionizing radiation (ultrasound, CT scan, mammogram, and dental x-ray). Confusion may have occurred for MRI scans as that procedure uses radio frequencies (a type of non-ionizing radiation). A positive response of “yes” that MRIs use radiation would therefore be technically correct due to the presence of non-ionizing radiation, when the intention was to query on patient exposure to ionizing radiation. To avoid negative impacts on knowledge scores due to uncertainty in the wording of the question, the question on radiation in MRI scans was therefore dropped and not included throughout the analyses.

Attitudes on radiation were measured in the questionnaire using 20 likert item questions with 7 response options (“strongly agree”, “somewhat agree”, “neither agree nor disagree”, “somewhat disagree”, “strongly disagree”, “unsure”, and choose not to answer). As with the knowledge questions, attitude measures were both adapted from previous studies (Bourassa et al. 2016; Stoutenborough et al. 2013; Corner et al. 2011; Poortinga et al. 2006; Whitefield et al. 2009) and newly developed for this research. The attitude questions were broken down into four categories: overall radiation attitudes (measuring across all 20 likert items; questions 1 through 20 of the survey); nuclear power attitudes, which segregated out the 6 questions specific to nuclear power plants (questions 1 through 6 of the survey), medical radiation attitudes, which segregated out the 6 questions specific to medicine (questions 7 through 12), and societal approach to radiation attitudes, which included general attitudes on radiation and how society should be using or approaching radiation (questions 16 through 20). Questions 13 through 15 were included in the overall attitudes, but not in any other sub-category due to their specific nature.

Attitudes towards radiation were also assessed via a risk assessment, in a manner similar to MacGregor (2002). Participants were presented with 12 sources of radiation (nuclear waste, nuclear power plants, radon gas, nuclear medicine, cosmic radiation, x-rays, background radiation, taking an airplane flight, smoke detectors,
nuclear weapons, CT scans, and naturally occurring radiation found in food; questions 46 – 57) and asked to assess the risk associated with that source. Response options were “no risk”, “low risk”, “moderate risk”, “high risk”, “unsure” and “choose not to answer”. This discrete assessment of the risk associated with particular sources of radiation differed from the treatment of risk within the earlier likert questions measuring attitudes. The latter required participants to make a simultaneous assessment of both risks and benefits (e.g. “The benefits associated with nuclear power exceed the risks” or “The benefits associated with medical radiation exceed the risks”). A person may find a particular source of radiation to be of high risk, but still be associated with a beneficial activity. Inclusion of risk assessment both as standalone items as well as in a comparison to benefits allows for changes in both of these aspects to be considered.

Finally, six likert items were used to assess participants’ attitudes on different nuclear technologies. Six different nuclear technologies that involve either the use or creation of radiation as a byproduct were provided to participants (medicine, electricity generation, industry, scientific research, sterilizing medical tools, and decontaminating food; questions 58 – 63), with six response options available (“strongly agree”, “somewhat agree”, “neither agree nor disagree”, “somewhat disagree”, “strongly disagree”, “unsure”, and “choose not to answer”).

In addition to the questions used to assess radiation knowledge and attitudes, the survey also included several demographic questions. These demographics act as important control variables within a regression model to more precisely delineate the relationship between radiation attitudes and knowledge. The demographic questions used in this survey were: age, sex, location of residence (urban or rural), if the participant had children, political affiliation, household income level, educational attainment, training in STEM (science, technology, engineering, and mathematics) fields, and employment status (questions 64 to 71 of the survey).
2.2.2 Participant Selection and Interviews

The Social Science Research Laboratory at the University of Saskatchewan in Saskatoon, Saskatchewan, Canada was contracted to select, contact, and conduct the interviews with participants. The surveys were completed between March 12 and March 21, 2018.

In order to obtain a representative and random sample of residents of Saskatchewan, random digit dialing methodology was used to contact potential participants. The target participant pool included any adult aged 18 years or over with a phone number with a Saskatchewan area code. Potential phone numbers were obtained from ASDE Survey Sampler located in Gatineau, Quebec, Canada. ASDE Survey Sampler conducts random digit dialing on phone numbers with a Saskatchewan area code and removes business and out-of-service numbers from an active phone number pool. Both cell phone and landline numbers are included in active pools, limiting bias introduced by excluding participants with only cell phone numbers. The pool provided by ASDE to the Social Science Research Laboratory was used as the initial potential pool of participants for this study. Phone numbers contained within the pool were chosen using WinCATI software, which randomly selects a phone number contained within the pool. A representative number of cell phone or landline numbers were selected based on available communications data from Statistics Canada.

A selected phone number was contacted five times before it was discarded from the pool. If the phone call was successfully answered, the interviewer asked to speak to the adult aged 18 years or older with the next closest birthday. If the selected individual was interested in participating in the survey, but was not available at the time of the call, a call back time was scheduled to complete the survey at the participant’s convenience. If the selected participant declined participation, the phone number was discarded from the pool.
Once a participant had agreed to participate, the Social Science Research Laboratory followed the script contained within the survey. The survey was conducted in a consistent order: likert items on attitudes, knowledge questions on radiation, risk assessment, and opinions on uses of radiation. The order of the sections within the knowledge portion of the questionnaire (true or false general questions, use of radiation in medicine, and radiation dose comparison) were also held consistent to avoid providing information to participants which may help on subsequent questions. To reduce the influence that individual questions order may have on responses, question order was then randomized within each section.

Each completed survey was provided with a unique number to facilitate tracking of responses during data analysis. Random phone numbers were selected and contacted until 500 participants had completed the survey.

2.2.3 Data Analysis

Knowledge questions were graded to provide an overall knowledge score. Correct answers were provided a score of 1, and incorrect answers a score of 0. Responses of “unsure” or refused questions were treated as incorrect answers and provided a score of 0.

Attitude questions were posed in a manner such that a positive attitude towards radiation was not always paired with a “strongly agree” response in order to account for agreement bias in responses (Hinz et al., 2007). During analysis, responses were coded such that a high score represented a favourable attitude towards radiation. Questions which were recoded to reverse the score are noted with an asterisk in the full survey found in Appendix A. Unsure responses were recoded as “neither agree nor disagree” for questions for which that response was available. When that not available, or when the question was refused, the response was treated as missing data. Likert items contained within the four attitude categories were summed into a single likert scale for analysis.
Four regression models were constructed to determine the predicted relationship between radiation knowledge and radiation attitudes. These four models related to four different dependent variables – overall attitude, nuclear power attitude, medicine attitude, and societal use of radiation attitude.

The demographic variables were included in all four of the regression models to control for confounding variables when examining the relationship between radiation knowledge and attitudes. Variables with multiple response categories (political affiliation, income level, education, and employment status) were combined from the original question categories due to low response rates for certain options. The resulting categories for the political affiliation variable were: Progressive Conservative, Liberal, New Democratic Party (NDP), Green Party, the Saskatchewan Party, no affiliation, and other parties; for annual household income level: $0 – 50,000, $50,000 – 100,000, $100,000 – 150,000, and over $150,000; for education: elementary school, secondary school, bachelor’s degree, technical/community college degree, and “advanced” degrees (including masters, PhDs, and professional designations); and for employment: employed (including part-time, full-time, and self-employment), students (including those who are working while students), unemployed (including those who are disabled and caregivers), and retired. Age was coded in the models as a continuous variable.

Binomial response demographic variables were included as dummy variables in the model (sex, location, children). Variables with more than two response categories were dummy coded for inclusion in the model (politics, income level, education, employment).

The reference variable used for each demographic variable is noted in the Results section for each model. Significant results for continuous variables (e.g. knowledge score or age) indicate the predicted change in the dependent variable for every one-point increase in the associated independent variable (all else being equal). For dummy variables, a significant response indicates the difference between the included variable and the reference variable (all else being equal). Models with other
reference variables but which did not provide additional significant information were created but omitted from the results.

2.2.4 Replacement of Missing Data

For many participants, surveys were not completed in full, with certain sensitive demographic variables (particularly income level, political affiliation, and age) often not being provided. 61 percent of the participants had fully complete datasets, with 5.3 percent of the data missing overall. Little’s Missing Completely at Random (MCAR) test was used to assess if the missing data was completely random (Little, 1988). For all of the delineations of the dependent variable (overall attitudes, nuclear radiation attitudes, medicine radiation attitudes, and society and radiation attitudes), Little’s MCAR test was significant ($p < 0.0005$ for all four cases). As Little’s test indicated the data was not missing at completely at random, multiple imputation rather than remove of participants with incomplete data provides the most reliable statistical method for addressing the missing data (Graham, 2009).

Multiple imputation was conducted in IBM SPSS version 24 to replace the missing data. 40 multiple imputation data sets were generated. With the extent of the missing data in the overall data set, 40 imputations is a sufficient number to avoid significant statistical power falloff (Graham et al., 2007). As each of the four regression models included a different dependent variable, multiple imputation was conducted four times, each time including the relevant dependent variable in the imputation process. As the number of variables included in the model makes the resulting imputation increasingly complex, the training in STEM fields was removed from the model. Preliminary analysis indicated that this variable demonstrated consistently non-significant relationships to any of the four dependent variables, and therefore its exclusion is not predicted to influence the analysis. The pooled results from the 40 imputed datasets are provided in the Results section.
2.2.5 Weighting

In order to ensure the sample used in the analysis best reflects the overall population of Saskatchewan, the results were weighted after generating the datasets through multiple imputation. The Social Science Research Laboratory provided weighting on the basis of three variables – sex, location (urban or rural), and age – data for which was available from Statistics Canada. Weighting variables were calculated and applied individually to the participants in each multiple imputation dataset.

2.3 Results

2.3.1 Internal Consistency and Reliability

Cronbach’s alpha was used to measure the internal consistency and reliability of the scales used to measure radiation attitudes and knowledge (Cronbach, 1951). Cronbach’s alpha was run on the four likert scales relating to each of the dependent variables (overall attitude, nuclear power attitude, medicine attitude, and societal approach to radiation attitude) as well as the knowledge battery of questions (Table 1).

It is recommended that Cronbach alpha values measure at least 0.50 to 0.60 for early stages of research, but do not exceed 0.90 as excessively high values indicate repetition of items rather than increased consistency (Streiner, 2003). The results for each of the radiation attitude categories as well as the knowledge battery demonstrate an acceptable level for Cronbach’s alpha.

2.3.2 Descriptive Statistics

Two hundred and ten (42 percent) of the participants were male and 290 (58 percent) were female. The average age of the participants was 59, with a minimum of 19 and a maximum of 95. 77 participants (15 percent) declined to provide an age. Three hundred and seventeen (63 percent) live in an urban location and 181 (36 percent) live in a rural location (two declined to provide a response - less than one percent). The breakdown of annual household income level was: 35 participants with a household income level less than $25,000 (seven percent), 97 between $25,000 and $50,000
Table 1: Cronbach’s alpha for radiation attitudes and knowledge

<table>
<thead>
<tr>
<th></th>
<th>Overall Attitude</th>
<th>Nuclear Power Attitude</th>
<th>Medicine attitude</th>
<th>Societal Approach to Radiation Attitude</th>
<th>Knowledge</th>
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<td>Cronbach’s Alpha</td>
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(19 percent), 83 between $50,000 and $75,000 (17 percent), 70 between $75,000 and $100,000 (14 percent), 42 between $100,000 and $125,000 (eight percent), 32 between $125,000 and $150,000 (six percent), 16 between $150,000 and $175,000 (three percent), and 34 over $175,000 (seven percent). Ninety-one either did not know or refused to answer (13 percent).

One hundred and fifteen (23 percent) of participants had training in science, technology, engineering, or mathematics, while 383 did not (77 percent) and 2 refused to answer (less than one percent). For the highest education level attained: 17 participants had elementary education (three percent), 162 had secondary education (32 percent), 155 had community college or a technical degree (31 percent), 111 had a bachelor degree (22 percent), 27 had a master’s degree (five percent), 16 had a professional designation (three percent), and 5 had a doctorate (one percent). Seven declined to answer the question (one percent).

Four hundred and eight of the participants had children (82 percent) while 89 did not (18 percent) and 3 declined to answer (less than one percent). For employment status: 81 were self-employed (16 percent), 137 were working full-time (27 percent), 32 were working part-time (six percent), nine were students who were also working (two percent), six were students and not working (one percent), 17 were caring for children or family members (three percent), 194 were retired (39 percent), 11 were unemployed (two percent), nine were unable to work due to disability (two percent), and four declined to provide a response (less than one percent).

For political affiliation: 47 associated with the Progressive Conservative party (nine percent), 35 the Liberal party (seven percent), 84 the New Democratic Party (17 percent), 16 the Green party (three percent), 145 the Saskatchewan party (29 percent), four the Western Independence party (less than one percent), 7 with other parties (one percent), and 74 did not know or had no declared affiliation (15 percent). Eighty eight declined to answer the question (18 percent).
For knowledge and attitude results, error is reported as plus or minus standard deviation. The average knowledge score was 15 correct answers out of 23 (± 3.8), with a low score of 5 and a high score of 23. The mean overall attitude score was 67 out of 100 possible points (± 14.1 points), with a low score of 27 points and a high score of 100. Twelve participants declined to answer at least one attitude question and therefore a score could not be calculated (two percent). The mean nuclear power radiation attitude was 18 out of a possible 30 (± 5.9 points), with a low of 6, a high of 30, and a missing score for seven participants (one percent). The mean medical radiation attitude score was 23 out of a possible 30 points (± 4.5 points), with a low of six, a high of 30, and a missing score for four participants (one percent). The mean societal approach to radiation attitude was 16 out of a possible 30 points (± 3.8 points), with a low of 5 points, a high of 25 points, and a missing score for 2 participants (less than one percent).

### 2.3.3 Relationship between Knowledge and Attitudes Using Multiple Linear Regression

#### 2.3.3.1 Overall Radiation Attitudes

The linear regression model (Figure 1) for overall radiation attitudes included females, those who live in rural locations, those without children, identified supporters of the Saskatchewan Party, $50,000 to $100,000 annual household income, secondary school, and retired as the reference variables. Age was included as a continuous variable.

The multiple regression was significant for all 40 of multiple imputations (p < 0.0005 for all datasets; p is the probability of obtaining the observed coefficients for the included variables if the null hypothesis is correct. In this case, the null hypothesis is that the model with no predictors and the model including the predictors described in the preceding paragraph are equal). The F statistic ranged from a minimum of 7.75 and a maximum of 10.27. The R-squared ranged from a minimum of 0.254 to a maximum of 0.319 (mean = 0.295), and the adjusted R-squared ranged from a minimum of 0.221 to
Figure 1 Overall Radiation Attitudes Regression Model: 500 participants completed a phone questionnaire on radiation attitudes and knowledge. Participants were selected by random digit dialing. The overall attitude metric summed participant responses on 20 likert items covering radiation attitudes, including aspects of nuclear power, medicine, and society’s use and approach to radiation. The knowledge variable calculated a score on 23 radiation knowledge questions. Responses were weighted by age, sex, and location to provide a representative sample of the Saskatchewan population. Reference variables were females, rural dwellers, those without children, identified supporters of the Saskatchewan Party, $50,000 to $100,000 annual household income, attainment of a secondary school degree, and retirees. Missing data was replaced via 40 multiple imputation datasets, with the figure providing the pooled result. The regression model was significant (p < 0.0005).
Knowledge was found to be a significant predictor of overall attitudes ($p < 0.0005$; in this circumstance, $p$ is the probability that the coefficient for the variable included in the model is 0 and has no predictive power on the dependent attitudes variable), where higher knowledge predicted a higher overall attitudes score. Among the demographic variables, males had a more favourable overall attitude towards radiation ($p = 0.001$), while Liberal and other political party affiliations had a lower overall attitude towards radiation than did participants who identified as supporters of the Saskatchewan Party ($p = 0.044$ and 0.018 respectively).

2.3.3.2 Nuclear Power Radiation Attitudes

The nuclear power radiation attitudes model (Figure 2) incorporated females, rural dwellers, those without children, identified supporters of ‘other’ political parties, $50,000$ to $100,000$ annual household income, secondary school, and retired as the reference variables. Age was included as a continuous variable.

The multiple regression was significant for all 40 of the multiple imputations ($p < 0.0005$ for all datasets). The $F$ statistic ranged from a minimum of 5.103 and a maximum of 7.409. The $R^2$ ranged from a minimum of 0.183 to a maximum of 0.246 (mean = 0.210), and the adjusted $R^2$ ranged from a minimum of 0.147 to a maximum of 0.212 (mean = 0.176).

Knowledge score was found to be a significant predictor of nuclear power radiation attitude ($p < 0.0005$), where higher knowledge scores predicted a higher nuclear power radiation attitude score. For demographic variables, males had a higher nuclear power attitude score than females ($p < 0.0005$), and nuclear power radiation attitude scores decreased as age increased ($p = 0.044$). All four of the Progressive Conservative affiliation ($p = 0.031$), NDP affiliation ($p = 0.045$), Saskatchewan Party Affiliation ($p = 0.011$), and no affiliation ($p = 0.043$) had higher nuclear power radiation attitude scores when compared to the ‘other’ political affiliation category. Both those in
Figure 2 Nuclear Power Radiation Attitudes Regression Model: Linear regression model for nuclear power radiation attitudes. 500 residents in Saskatchewan completed a phone questionnaire on radiation attitudes and knowledge. Participants were selected by random digit dialing. The nuclear power radiation attitude metric summed participant responses on 6 likert items. The knowledge variable calculated a score on 23 radiation knowledge questions. Responses were weighted by age, sex, and location to provide a representative sample of the Saskatchewan population. Reference variables included in the model were females, rural dwellers, those without children, other political affiliation, $50,000 to $100,000 annual household income, secondary school, and retired participants. Missing data was modelled via 40 multiple imputation datasets. The presented result provides the pooled statistics. The regression model was significant (p < 0.0005).

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the students (p = 0.017) and unemployed (p = 0.016) employment categories had lower nuclear power attitudes when compared to those in the retired employment category.

2.3.3.3 Medical Radiation Attitudes

The medical radiation attitudes model (Figure 3) incorporated females, rural dwellers, those without children, identified supporters of the Saskatchewan Party, $150,000 and over in annual household income, secondary school, and retired participants as the reference variables. Age was included as a continuous variable.

The multiple regression was significant for all 40 of the multiple imputations (p < 0.0005 for all datasets). The F statistic ranged from a minimum of 5.195 and a maximum of 6.873. The R-squared ranged from a minimum of 0.186 to a maximum of 0.232 (mean = 0.209), and the adjusted R-squared ranged from a minimum of 0.150 to a maximum of 0.198 (mean = 0.175).

Knowledge score was found to be a significant predictor of medicine radiation attitude (p < 0.0005), where higher knowledge scores predicted a higher medicine radiation attitude score. For demographic variables, annual household income between $0 and $50,000 (p = 0.037) and between $100,000 and $150,000 (p = 0.028) predicted a lower medicine radiation attitude score compared to a household income over $150,000. Being employed predicted a lower medicine radiation attitude score than those who were retired (p = 0.031).

2.3.3.4 Societal Approach to Radiation Attitudes

The societal approach to radiation attitudes model (Figure 4) incorporated females, rural dwellers, those without children, the Saskatchewan Party, $50,000 to $100,000 annual household income, secondary school, and retired participants as the reference variables. Age was included as a continuous variable.
Figure 3 Medical Radiation Attitudes Regression Model: Linear regression model for medicine radiation attitudes. 500 residents in Saskatchewan completed a phone questionnaire on radiation attitudes and knowledge. Participants were selected by random digit dialing. The medicine radiation attitude metric summed participant responses on 6 likert items. The knowledge variable calculated a score on 23 radiation knowledge questions. Responses were weighted by age, sex, and location to provide a representative sample of the Saskatchewan population. Reference variables included in the model were females, rural dwellers, those without children, identified supporters of the Saskatchewan Party, $150,000 and over annual household income, secondary school, and retired participants. Missing data was modelled via 40 multiple imputation datasets. The presented result provides the pooled statistics. The regression model was significant (p < 0.0005).
Figure 4 Societal Approach to Radiation Regression Model: Linear regression model for societal approach to radiation attitudes and knowledge. 500 residents in Saskatchewan completed a phone questionnaire on radiation attitudes and knowledge. Participants were selected by random digit dialing. The societal approach to radiation attitude metric summed participant responses on 5 likert items. The knowledge variable calculated a score on 23 radiation knowledge questions. Responses were weighted by age, sex, and location to provide a representative sample of the Saskatchewan population. Reference variables included in the model were females, rural dwellers, those without children, identified supports of the Saskatchewan Party, annual household income between $50,000 and $100,000, attainment of secondary school, and retired participants. Missing data was modelled via 40 multiple imputation datasets. The figure provides the pooled results. The regression model was significant (p < 0.0005).

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The multiple regression was significant for all 40 of the multiple imputations ($p < 0.0005$ for all datasets). The F statistic ranged from a minimum of 7.324 and a maximum of 9.166. The R-squared ranged from a minimum of 0.243 to a maximum of 0.287 (mean = 0.266), and the adjusted R-squared ranged from a minimum of 0.210 to a maximum of .256 (mean = 0.234).

Knowledge score was found to be a significant predictor of societal approach to radiation attitude ($p < 0.0005$), where higher knowledge scores predicted a higher societal approach to radiation attitude score. For demographic variables, males were predicted to have a higher societal approach to radiation attitude score as compared to females ($p = 0.009$). All of the Progressive Conservatives ($p = 0.038$), Liberal Party ($p = 0.011$), NDP ($p = 0.037$), and no affiliation ($p = 0.028$) were predicted to have lower societal approach to radiation scores compared to the Saskatchewan party.

2.4 Discussion

Previous research has explored the relationship between radiation knowledge and attitudes. Both Stoutenborough et al. (2013) and Sturgis and Allum (2004) employed similar regression modeling to explore the impact of nuclear power knowledge on subsequent attitudes, with both studies finding a positive relationship between these two elements. Costa-Font et al. (2008) also found a positive relationship between knowledge and attitudes regarding radiation waste, but noted that this relationship is modulated by political beliefs and that the relationship between knowledge and attitudes may not be simple and direct. More generally, other studies have used this methodology to look at the relationship between general science knowledge and attitudes (e.g. Evans and Durant, 1995) with similar results. A meta-analysis conducted by Allum et al. (2008) found a minor positive correlation between the general knowledge of scientific facts and subsequent attitudes towards science.
The results from this chapter follow in the vein of this previous work, and provide evidence to support a relationship between one's knowledge about radiation and attitudes towards radiation. This relationship held true for all of the different types of radiation attitude queried - overall attitudes as well as attitudes specific to nuclear power, medical radiation, and societal approach to radiation. In each case, the regression modelling indicated that more knowledge about radiation results in a more favourable attitude towards radiation. The model was inclusive of multiple demographic variables which may have attenuated or influenced the relationship between knowledge and attitudes (such as the influence of politics found by Costa-Font and colleagues), and therefore provide at least some evidence in support of the information deficit model.

The demographic variables included in the model are those that have been included in multiple previous studies regarding radiation attitudes among the lay public, most of which focus on the development of nuclear power. Males consistently show a more favourable attitude towards nuclear power than do females (Corner et al. 2011; Costa-Font et al. 2008; Ansolabehere and Konisky 2009; Stoutenborough et al. 2013; Whitfield et al. 2009). The results in this research followed suit, with males demonstrating a more favourable attitude towards radiation when overall attitudes, nuclear power attitudes, and societal approach to attitudes were considered. The only instance where this difference did not occur was for medical radiation, a result similar to that found by Takakuwa et al (2010).

Age was only a significant predictor of attitudes for nuclear power radiation, in which older individuals had a lower attitude towards nuclear power radiation. The existing literature on the influence of age on nuclear power attitudes is divided. While some studies (e.g. Corner et al. 2011) find a more positive attitude towards nuclear power among older individuals, others find a negative relationship (e.g. Ansolabehere and Knoisky 2009) or no significant relationship at all (e.g. Costa-Font et al. 2008;
Stoutenborough et al. 2013, Whitfield et al. 2009). The variability in linking age with nuclear power attitudes results suggests a population-specific relationship. In Saskatchewan, the results of this study indicate a negative association of nuclear power among older residents.

Location, children, and education were all not significant in each of the models built for this study (p > 0.05). The results for location and education match the consensus of previous research (Costa-Font et al. 2008; Ansolavehere and Konisky 2009; Stoutenborough et al. 2013; Whitfield et al. 2009). The influence of children on radiation attitudes, particular among mothers, has been proposed as accounting for the difference seen between men and women in radiation attitudes. Previous work has suggested that the child birth role of mothers lends a natural, biological disposition towards higher risk perception. However, a closer investigation of the data suggests that the differences between men and women are not biological or due to child rearing, but rather sociopolitical and influenced by control and benefit of the technology providing the risk (Slovic, 1999). Morioka's (2014) investigation of radiation risk in Japan following the Fukushima disaster supports this conclusion. In Japan, where women maintain a more historical domestic role, men in the workforce were more concerned with the economic consequences of Fukushima, whereas women in the home focused on the risks of radiation. Freudenburg and Davidson (2007) demonstrated that economics can override gender differences. Employed mothers where economic concerns were visible demonstrated low concern for radiation risk as compared to mothers who were not subject to such economic influences.

The role of politics in forming radiation attitudes was inconsistent in this study. In general, supporters of the Saskatchewan Party, a conservative political party in Saskatchewan, had a more favourable view towards radiation. However, this relationship was tenuous, and did not occur when the radiation was specific to medicine
or nuclear power. The result for medicine is perhaps unsurprising, given the low influence of most demographic variables on medical attitudes. Evidently medical radiation is an equalizer of attitudes, where even those who oppose radiation in other applications accept it when it comes to its use in medicine. In considering attitudes towards science in general, those on the left side of the political spectrum tend to have a lower attitude as compared to those on the right (Sturgis and Allum 2004). This held true when Corner et al (2011) applied this to nuclear power in specific. However, that result is not consistent across the literature. Ansolabehere and Konisky (2009) and Whitfield et al. (2009) found no influence of politics on nuclear power attitudes, while Costa-Font et al. (2008) found that any declaration of political affiliation, regardless of party or where that party lay on the political spectrum, led to lower nuclear power attitudes. As a whole, the direct relationship between political affiliation and radiation attitudes remains murky. Local political influences should therefore be assessed in each population rather than assuming the relationship in one population will hold true among others.

Income was not a significant predictor for any category of radiation attitude with the exception of medicine, in which the highest income bracket (annual household income over $150,000) had a more favourable attitude towards medical radiation than did either of the $0 - $50,000 or $100,000 - $150,000 annual household income brackets (worth noting is that the $50,000 - $100,000 annual household income bracket also was near to being significantly different from the $150,000 and above bracket). Previous studies also failed to find a significant link between income level and nuclear power attitudes (Ansolabehere and Konisky 2009; Stoutenborough et al. 2013; Whitfield et al. 2009), while Corner et al. (2011) found that a higher socioeconomic class was positively associated with a more favourable view towards nuclear power.

The more positive attitude towards medical radiation demonstrated by the highest income bracket is intriguing in light of the free health care experienced by those
residing in Saskatchewan. It could be logically predicted that as income plays no barrier to access, it would not play a significant role in determining attitudes towards medical radiation. The role of income on medical use in Canada has been explored. Dunlop et al. (2000) found that income had no bearing on the probability of a single visit to a primary care physician, however lower socioeconomic individuals were more likely to make repeated visits to a primary care physician but less likely to visit specialists. Low income individuals are also more likely to utilize emergency rooms than high income groups (Khan et al., 2011), indicating that simple usage of physician services is not necessarily tied to income determinants. In their review of radiation therapy usage in Canada, Gillan et al. (2012) were unable to find a consistent link between income levels and utilization of radiation therapy. It remains uncertain as to why the highest income bracket had a more favourable attitude towards radiation in this study.

Perhaps somewhat incongruently, retirees (who one would expect to be older) had a higher attitude towards nuclear power than did students or unemployed individuals. Retirees also had a higher attitude towards medical radiation when compared to employed individuals. Employment status was typically not included in the surveyed previous research specific to radiation, although in their review Sturgis and Alum (2004) note no relationship between employment status and general attitude towards science.

As this study was primarily focused on the influence of knowledge on radiation attitudes, efforts were not made to explore in detail the relationships between demographic variables and the attitudes held towards radiation. Explanations for the relationships between the demographic variables included in these regression models with attitudes towards radiation remains an avenue for future research. What is critical for the purposes of this discussion is that, even when controlling for various
demographic criteria, knowledge has been demonstrated to be a consistently significant predictor of radiation attitudes.

2.5 Concluding Remarks

The series of linear regression models built exploring the relationship between radiation knowledge and attitudes provide consistent evidence to support the hypothesis that knowledge on the topic of radiation can positively impact attitudes towards radiation. The result was consistent. For all four attitude dependent variables, an increase result on the radiation knowledge test significantly predicted higher scores on radiation attitudes.

The link between radiation knowledge and attitudes supports the supposition that direct education may be able to shape attitudes. The logical through line is clear – as higher knowledge scores predict higher attitude scores, increasing an individual’s knowledge would reasonably be expected to increase their attitude scores.

This prediction was explored through a controlled experiment methodology. Willing participants who completed the survey on radiation knowledge and attitudes were separated into two groups. The first was provided with direct education on radiation, and the second was not and therefore acted as a control group. Comparison in the change in attitudes between the education and control groups will provide additional evidence on the relationship and influence, or lack thereof, that knowledge of radiation can have on informing attitudes towards radiation.
CHAPTER THREE: EFFECTS OF EDUCATION ON RADIATION ON RADIATION ATTITUDES IN A CONTROLLED EXPERIMENT

3.1 Introduction

The results from the regression analysis on radiation attitudes in Chapter 2 indicate that knowledge about radiation is a significant predictor of radiation attitudes. This holds true for all aspects of radiation attitudes, including nuclear power radiation, medical radiation, societal approach to radiation, and overall radiation attitudes. To further explore the relationship between knowledge and attitudes, a direct education experiment was conducted. In this experiment, 80 voluntary participants who completed the first telephone survey used to construct the regression models were separated into two groups – an education group which received direct education on radiation, and a control group who did not receive this education packet. The survey on radiation knowledge and attitudes was then repeated to test for any changes in knowledge and attitudes which could be attributed to the educational intervention.

3.2 Methods

3.2.1 Participant Pool

At the completion of telephone survey on radiation attitudes and knowledge described in Chapter 2, participants were asked to self-select for continued participation in the research project. Participants were informed that this process could include reading through education materials about radiation and completion of a second survey. At this time, participants were not informed that the intent of the research was to observe if direct education on radiation had any subsequent impacts on radiation attitudes. Participants who agreed to continue in research project were requested to provide a contact phone number or email address along with a first name to ensure contact could be re-established with the participant. This contact information was paired
to a unique number identifier for the initial survey to allow tracking of responses on the initial survey and the final survey completed following the intervention.

3.2.2 Participant Recruitment and Treatment Groups

Distribution of the education materials to participants and completion of the follow-up survey for both education and control treatment groups occurred between March 31 and June 21, 2018. Participants were randomly sorted into either the education treatment group or the control treatment group. Follow-up contact was attempted either through email or a phone call as requested by the participant at the end of the initial survey. Contact was attempted three times on non-consecutive days before the participant was removed from the prospective participant pool.

Once contact was established, participants were reminded of the initial survey that they had completed, and again asked for consent to continue on in the research project. At this time, participants were informed of the requirements of continued participation as appropriate for the treatment group to which they had been assigned (i.e. the control group was informed they would need to complete a second questionnaire about radiation, while the education group was informed their continued participation would include reading an educational booklet about radiation, watching videos online about radiation, and completing a second questionnaire). Participants who indicated that they did not wish to continue on as a participant were removed from the participant pool.

As higher attrition was anticipated for the education treatment group than the control treatment group given the higher time demands of the educational intervention, completion of a satisfactory number of participants in the education group was completed prior to initiation of the control group. As a result of high initial attrition in participants assigned to the education treatment group, additional participants were randomly re-assigned from the control treatment group to the education treatment
group. This dynamic process resulted in a completion of the research project by 43 participants in the education treatment group and 37 participants in the control group.

To ensure that any differences between the treatment groups were due to the intervention and not to other extraneous variables, the treatment groups were compared on the demographic data obtain in the initial telephone survey (gender, age, urban/rural location, children, education in STEM fields, educational attainment, employment, income level, and political affiliation). A t-test was used for the continuous age variable, and chi-squared test of homogeneity or Fisher’s exact test for ordinal and dichotomous variables respectively. Missing demographic data was replaced using multiple imputation with 40 data sets as described in section 2.2.4.

3.2.3 Educational Materials

To facilitate increased knowledge about the science and use of radiation, education materials on radiation were provided to the education treatment group. These materials were designed to inform participants on the scientific nature and application of radiation. Previous work on the education of non-experts on radiation was adapted for these materials (MacGregor, 2002). The materials consisted of an educational packet (Appendix B) with five short chapters along with accompanying online videos (Appendix C). While participants were able to move through the education materials at their own pace, they were designed to take around one hour to complete.

Given reasonable expectations for the amount of time a participant would be willing to dedicate to the research project, the education materials could not be entirely comprehensive. Key concepts were selected and conveyed using simple and accessible language. By design, the education materials were written to allow participants in the education treatment group to gain the knowledge to correctly answer the knowledge questions contained within the radiation questionnaire. Directly mirroring the knowledge
questions with information in the education materials allowed for the level of education imparted to the participants to be measured.

The education materials were divided into six chapters:

3.2.3.1 Chapter One - Introduction to Radiation

The first chapter was designed to provide a basic overview of the science of radiation. The discussion included:

- an introduction of the concepts of matter and atoms;
- a description of radiation as the movement of energy;
- an overview of the concepts of ionizing and non-ionizing radiation (including how these two types of radiation interact differently with matter and atoms);
- examples of ionizing radiation (alpha particles, beta particles, x-rays, gamma rays, and neutrons) and the differences between these types of ionizing radiation;
- a discussion on whether radiation can make other objects become radioactive; and
- a brief overview of how radiation is measured.

The intent of the first chapter was to teach the participants about the basics of radiation to enable a discussion on the application of radiation, different sources of radiation, and how radiation can impact the human body.

3.2.3.2 Chapter Two - Radiation’s Impact on the Human Body

The second chapter introduced the concepts of what occurs when a person is exposed to radiation. The chapter introduced the concepts of cells and DNA, in particular how these structures make up our bodies. The outcomes of radiation exposure on these structures was discussed. Also, participants were provided with
information on the levels of exposure at which health negative consequences can be expected and distinguished from natural levels of cellular damage, death, and DNA mutation.

3.2.3.3 Chapter Three - Natural Sources of Ionizing Radiation

The third chapter of the educational materials introduced the concept of naturally occurring radiation, and described several of these sources, including cosmic radiation, terrestrial radiation, and ingestion and internal radiation. Participants were provided with a chart describing the annual dose of background radiation in milliSieverts for citizens of different cities in Canada. This list included Regina, Saskatchewan, a city located in the home province of the participants. While participants would not yet be expected to contextualize these doses as compared to other radiation sources like nuclear power plants or medical procedures, they were introduced at this time. The natural levels of radiation exposure were then revisited and compared with human-controlled sources of radiation in the fifth chapter.

3.2.3.4 Chapter Four – Human-Controlled Sources of Ionizing Radiation

The fourth chapter discussed the manner in which radiation is harnessed and used by people to accomplish specific aims. Several sources were introduced, with a specific focus being placed upon radiation as it is created and used in nuclear power plants and in medicine. Considerable information was provided on nuclear power plants, including how nuclear power plants use the nuclear chain reaction to generate electricity, how radiation is also created during this process and how it is contained, other safety mechanisms of nuclear power plants, and the treatment of nuclear waste. Regarding medicine, the participants were informed on different medical procedures that use ionizing radiation, the doses that can be received from some of these procedures, and other procedures that do not use ionizing radiation.
3.2.3.5 Chapter Five - Exposure Comparison

The fifth chapter presented a comparison of radiation from different sources. These included a variety of sources from human-driven activities (including smoke detectors, coal power plants, nuclear power plants, construction activities, taking an airplane flight, fertilizers, and various medical procedures), as compared to what a person in Regina, Saskatchewan, Canada would be exposed to from natural background sources of radiation. The intent of this chapter was to provide context on the amount of radiation a person could be exposed to in various situations, and to provide a comparison to what a person would be exposure to naturally in the absence of any human-controlled sources.

3.2.3.6 Chapter Six - Other Uses for Radioactive Materials

The final chapter discussed in brief other uses of radiation that were not elaborated upon in depth in the education materials. These topics included the use of radiation in scientific research (by way of example, the Canadian Light Source synchrotron in Saskatoon, Saskatchewan), using radiation to sterilize medical equipment and food, and the use of radiation in industrial practices.

A list of references used to compile the education materials was also provided to the participants. These references enabled interested participants to verify the information provided in the education booklet.

3.2.3.7 Accompanying Educational Videos

A series of accompanying videos were provided to the participants to enhance the learning experience. Five videos mirrored the chapters of the education booklet, and contained a visual and verbal representation of the same information. Animations in the video were developed in association with the Centre for Continuing Education at the University of Regina, Regina, Saskatchewan, Canada. Periodic questions in the video, similar to questions asked in the knowledge section of the questionnaire, helped the
participants to focus on critical information and to self-test knowledge acquisition. The videos were loaded online onto a private YouTube channel. Participants who were selected into the education treatment group were provided access to the videos via links sent in an email. Participants were then able to proceed through the education booklet and the videos at their own pace.

### 3.2.4 Second Application of the Radiation Questionnaire

Following completion of the education materials, participants were asked to again complete the questionnaire on radiation knowledge and attitudes (Appendices D and E). Application of the questionnaire was identical to the first time participants were asked to complete it, with the exception that demographic questions were omitted. The second questionnaire was completed for the entirety of the education group prior to commencement of the questionnaire for the control group. In this manner, any outside influence that could potentially influence radiation attitudes (e.g. a nuclear power plant issue becoming public in the news) would be captured in the control group. Functionally, as attrition was expected to be higher in the education group as compared to the control group, the education group was also completed first in order to ensure a sufficient number of participants in each group.

Following completion of the second survey, the objectives of the research were explained to all participants (see Appendix F for participant debrief script).

### 3.2.5 Data Analysis

Education and control treatment groups were compared on the demographic variables included in the initial application of the questionnaire (age, gender, education attainment, employment situation, income level, children, urban/rural location, political affiliation, and background in STEM). For the continuous age variable, the two groups were compared using a t-test. All other demographic variables were assessed using the
chi-squared test of homogeneity or, where representative values were not sufficient in each category, Fisher's exact test.

Analysis of attitude change due to an intervention can occur through several different statistical analyses. In order to test the impact that the education materials had on radiation knowledge and attitudes, several different statistical approaches were employed. In part, this occurred due to the violation of assumptions that occurred in the results (e.g. the assumption of normality for t-tests, Levene’s test for homogeneity of variances and Box’s test of equality of covariance for mixed model ANOVA). The statistical analyses were performed on each of knowledge, overall radiation attitudes, nuclear power radiation attitudes, medical radiation attitudes, and societal approach to radiation attitudes. When present, errors are reported as plus/minus standard deviation.

The statistical tests used in the analysis were:

1) Mixed-model ANOVA (Broughton et al., 2011; Sheeber et al., 1996);
2) T-tests for all pair-wise groupings of the education and control groups, before and after the intervention, or Welch’s t-test when Levene’s test for homogeneity of variances was significant (Zientek et al., 2016);
3) Mann-Whitney U tests for all pair-wise groupings of the education and control groups, before and after the intervention (a non-parametric alternative to the t-test);
4) Gain score analysis between the education and control groups (Zientek et al., 2016; Oakes and Feldman, 2001; Sheeber et al., 1996);
5) ANCOVA analysis with the Johnson-Neyman procedure, incorporating pre-intervention scores as a co-variate (Zientek et al., 2016; Rausch et al., 2003; Oakes and Feldman, 2001; Sheeber et al., 1996; Johnson and Fay, 1950; D’Alonzo, 2004). The procedure was applied at an alpha of .05.

The results of each of these statistical tests on knowledge, overall radiation attitudes, nuclear power radiation attitudes, medical radiation attitudes, and societal approach to
radiation attitudes is presented in section 3.3. A summary of the results is provided in Table 3 and Table 4 in section 3.3.7.

3.3 Results

3.3.1 Demographic Comparison of Control and Education Groups

Prior to testing of the impact of education on radiation knowledge and attitudes, the control and education groups were compared on key demographic criteria to support that any subsequent difference between the groups could be attributed to the educational intervention rather than other confounding factors. For variables with missing data that was replaced with missing value analysis (income, politics) the range of p-values from the 40 generated data sets is provided. For some of the demographic variables, sufficient values for each category were achieved in some of the generated data sets, but not others. When this circumstance occurred, both the results from the chi-squared test of homogeneity and Fisher’s exact test were reported.

The two groups were compared on the following factors: age (t-test p = 0.740), gender (chi-squared test of homogeneity p = 0.591), education attainment (chi-squared test of homogeneity p = 0.835), employment situation (Fisher’s exact test p = 0.180), income level (chi-squared test of homogeneity p = 0.145 - 0.484; Fisher’s exact test p = 0.169 - 0.459), children (chi-squared test of homogeneity p = 0.562), urban/rural location (chi-squared test of homogeneity p = 0.473), political affiliation (chi-squared test of homogeneity p = 0.104 - 0.265; Fisher’s exact test p = 0.108 - 0.303), and background in STEM (chi-squared test of homogeneity p = 0.930 ). The differences between the control and education groups were not statistically significant for any of these factors.

Together, the control and education group demographic characteristics were also compared to those found in the general Saskatchewan population. A summary of this comparison is provided in Table 2.
Table 2: Participant demographics compared to Saskatchewan population

<table>
<thead>
<tr>
<th>Variable</th>
<th>Participants</th>
<th>Saskatchewan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>Female – 56%</td>
<td>Female – 50%</td>
</tr>
<tr>
<td></td>
<td>Male – 43%</td>
<td>Male – 50%</td>
</tr>
<tr>
<td>Location</td>
<td>Rural – 34%</td>
<td>Rural – 35%</td>
</tr>
<tr>
<td></td>
<td>Urban – 66%</td>
<td>Urban – 65%</td>
</tr>
<tr>
<td>Education</td>
<td>Secondary – 24%</td>
<td>Secondary – 30%</td>
</tr>
<tr>
<td></td>
<td>Technical – 38%</td>
<td>Technical – 28%</td>
</tr>
<tr>
<td></td>
<td>Bachelors – 24%</td>
<td>Bachelors – 13%</td>
</tr>
<tr>
<td></td>
<td>Advanced – 15%</td>
<td>Advanced – 4%</td>
</tr>
<tr>
<td>Employment</td>
<td>Employed – 60%</td>
<td>Employed – 63%</td>
</tr>
<tr>
<td></td>
<td>Unemployed – 6%</td>
<td>Unemployed – 5%</td>
</tr>
<tr>
<td></td>
<td>Student – 1%</td>
<td>Not in Labour Force – 32%</td>
</tr>
<tr>
<td></td>
<td>Retired – 33%</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>Median – 59</td>
<td>Median – 37.8</td>
</tr>
<tr>
<td>Household Income</td>
<td>Median – $50,000 - $100,000</td>
<td>Median – $75,412</td>
</tr>
</tbody>
</table>
Compared to the general Saskatchewan population, participants were more likely to be female, were older than the general population, and were better educated with more participants having education beyond secondary compared to the general population.

3.3.2 Impact of Education on Knowledge Scores

3.3.2.1 Descriptive Statistics - Knowledge

The maximum score on the knowledge test was 23 correct answers. The mean correct answers for the control group on the first application of the knowledge test was 16.65 ± 3.51 correct answers. On the second application of the knowledge test, the mean score for the control group was 17.32 ± 3.47 correct answers. The mean correct answers for the education group on the first application of the knowledge test was 16.60 ± 3.58 correct answers. On the second application of the knowledge test, which followed the education intervention, the mean score was 21.67 ± 1.24 correct answers.

Of participants in the control group, 20 (54%) showed an increase in knowledge between the first and the second application of the test, while 10 (27%) showed a decrease and 7 (19%) showed no change. For the education group, 41 participants (95%) showed an increase in knowledge between the first and the second applications of the test, while 2 (5%) showed no change.

3.3.2.2 Shapiro-Wilk Test for Normality - Knowledge

The Shapiro-Wilk test for normality was not significant for both the education and control groups prior to the educational intervention (control p = 0.116; education p = 0.147), but was significant for both groups on the second application of the questionnaire, indicating non-normal distributions (control p = 0.028; education p < 0.0005; Figure 5).
Figure 5 Distribution of Knowledge Scores Before and After Educational Intervention: Distribution of scores on a 23-question radiation knowledge questionnaire. Maximum score is 23. The first questionnaire was administered over the phone to 500 participants, of which 80 continued in the project and whose scores are represented in the figure. Continuing participants were separated into 2 groups: a control group (n = 37) and an education group (n = 43) which was administered an educational package on radiation. Participants were subsequently administered the same questionnaire for a second time. (a) distribution of radiation knowledge scores for the control group on the first administration of the questionnaire (Shapiro-Wilk test for normality not significant, p = 0.116); (b) distribution of radiation knowledge scores for the education group on the first administration of the questionnaire (Shapiro-Wilk test for normality not significant, p = 0.147); (c) distribution of radiation knowledge scores for the control group on the second administration of the questionnaire (Shapiro-Wilk test for normality significant, p = 0.028); (d) distribution of radiation knowledge scores for the education group on the second administration of the questionnaire following the educational intervention (Shapiro-Wilk test for normality significant, p < 0.0005).
3.3.2.3 Mixed Model ANOVA - Knowledge

The mixed model ANOVA estimated marginal means plot indicated an interaction between the treatment group and the two applications of the questionnaire (Figure 6), which was found to be statistically significant (p < 0.0005). However, Levene’s test for homogeneity of variances was violated for the posted-test (p < 0.0005). Box’s test of equality of covariance was also violated (p < 0.0005).

3.3.2.4 T-tests - Knowledge

To determine the point of significance for the mixed model ANOVA, and due to the violation of Levene’s test for homogeneity and Box’s test of equality of covariance, independent t-tests were run between subjects of the control and education groups before and after the intervention, and within subjects for the control and education groups before and after the intervention.

There was no significant difference between the control and education groups prior to the intervention (Levene’s test p = 0.612; t-test p = 0.864). A significant difference did exist between the control and education groups following the intervention (Levene’s test p < 0.0005; Welch’s t-test p < 0.0005). The mean post-intervention knowledge scores for the education group were 4.2 points higher than for the post-intervention control group (95% confidence interval 2.9 – 5.4).

There was no significant difference in the knowledge scores in the control group before or after the intervention (Levene’s test p = 0.834; t-test p = 0.408). There was a significant difference in the knowledge scores for the education group before and after the intervention (Levene’s test p <0.0005; Welch t-test p < 0.0005). The mean knowledge score for the education group increased by 5.0 points (95% confidence interval 3.8 – 6.2).
Figure 6 – Estimated Marginal Means of Knowledge Scores: Estimated marginal means plot from a mixed model ANOVA on knowledge scores on a 23-question radiation knowledge questionnaire. The first questionnaire was administered over the phone to 500 participants, of which 80 continued in the project and whose responses are represented in the results. Continuing participants were separated into 2 groups: a control group (n = 37) and an education group (n = 43) which was administered an educational package on radiation. Participants were subsequently administered the same questionnaire for a second time. The interaction between the two treatment groups and the two applications of the questionnaire was significant (p < 0.0005). However, Levene’s test for homogeneity of variances was violated for the posted-test (p < 0.0005). Box’s test of equality of covariance was also violated (p < 0.0005). Error bars represent 95% confidence intervals.
3.3.2.5 Mann Whitney U Test - Knowledge

Due to the violation of normal distributions found in the Shapiro-Wilk test, knowledge scores were also assessed using the Mann Whitney U test. As with t-tests, Mann Whitney U tests were run between subjects of the control and education groups before and after the intervention, and within subjects for the control and education groups before and after the intervention.

There was no significant difference in the median overall knowledge score between the control and education groups prior to the intervention (p = 0.850). Distributions for the two groups were similar based on visual inspection. The distributions were not visually similar for the control and education groups following the intervention (Figure 7), and the distributions were significantly different (p < 0.0005).

The distributions for the control group before and after the intervention were visually similar. There was no significant difference in the median score of the control group before or after the intervention (p = 0.400). The distributions for the education group before and after the intervention were not visually similar (Figure 8), and the distributions were significantly different (p < 0.0005).

3.3.2.6 Gain Scores - Knowledge

As an alternative method of analysis, gain scores on the knowledge test were compared between the education group and the control group. The mean gain score for the education group was 5.0 and the mean gain score for the control group was 0.68. The difference in gain scores was significant (Levene’s test p = 0.027; Welch’s t-test p < 0.0005), with the education group gain score being 4.4 points higher than the control group gain score (95% confidence interval 3.1 – 5.7)
Figure 7 – Mann Whitney U Test Distributions for Knowledge Scores Between Control and Education Groups: Mann Whitney U test distribution comparison of scores on a 23-question radiation knowledge questionnaire. The first questionnaire was administered over the phone to 500 participants, of which 80 continued in the research project and whose scores are represented in the results. Continuing participants were separated into 2 groups: a control group (n = 37) and an education group (n = 43) which was administered an educational package on radiation. Participants subsequently were administered the same questionnaire for a second time. (a) Comparison of distributions between the control and education groups on the first questionnaire. There was no difference in the median knowledge score (p = 0.850); (b) Comparison of distributions between the control and education groups on the second questionnaire. The distributions were significantly different (p < 0.0005).
Figure 8 Mann Whitney U Test Distributions for Knowledge Scores Within Control and Education Groups: Mann Whitney U test distribution comparison of scores on a 23-question radiation knowledge questionnaire. The first questionnaire was administered over the phone to 500 participants, of which 80 continued in the research project and whose scores are represented in the results. Continuing participants were separated into 2 groups: a control group (n = 37) and an education group (n = 43) which was administered an educational package on radiation. Participants subsequently were administered the same questionnaire for a second time. (a) Comparison of distributions for the control group between the second (left panel) and first (right panel) administration of the questionnaire. There was no difference in the median knowledge score (p = 0.400); (b) Comparison of distributions for the education group between the second (left panel) and first (right panel) administration of the questionnaire. The distributions were significantly different (p < 0.0005).
3.3.2.7 ANCOVA Analysis with Johnson-Neyman Procedure - Knowledge

Typical ANCOVA analysis requires homogeneity of regression slopes between the two groups (e.g. the control and education treatment groups) across the spectrum of the covariate (in this case, radiation knowledge scores on the first application of the questionnaire). Due to bounding of maximum scores on the knowledge test (or any of the attitude scores) this assumption was often violated. Application of the Johnson-Neyman procedure overcomes this violation and allows for discovery of regions of significance between the education and control post-intervention knowledge scores along the spectrum of pre-intervention scores (Johnson and Fay, 1950; D’Alonzo, 2004).

The post-intervention estimated means for the education group were significantly higher than the post-intervention estimated means for the control group when the pre-intervention knowledge score was 21 points or fewer. The education and control group estimated means were not significantly different for pre-intervention knowledge scores of 22 or 23 points, with 23 points being the highest possible score (Figure 9).

3.3.2.8 Summary – Influence of Educational Intervention on Knowledge Scores

The combined results of a mixed model ANOVA, t-tests, Mann Whitney U tests, and gain scores indicated a significant increase in knowledge for the education group as compared to the control group. The ANCOVA analysis with Johnson-Neyman procedure specified that the increase in knowledge for the education group was significantly different from the control group when pre-intervention scores were 21 points or fewer.
Figure 9 Johnson-Neyman Analysis for Knowledge Scores: Johnson-Neyman analysis of the difference between the control and education treatment groups on radiation knowledge scores. The first questionnaire was administered over the phone to 500 participants, of which 80 continued in the research project and whose scores are represented in the results. Continuing participants were separated into 2 groups: a control group (n = 37) and an education group (n = 43) which was administered an educational package on radiation. Participants subsequently were administered the same questionnaire for a second time. The Johnson-Neyman procedure compared differences between the control and education groups radiation knowledge scores on the second questionnaire along the spectrum of knowledge scores on the first questionnaire. Second questionnaire knowledge scores were significantly higher for the education group when the first questionnaire knowledge score was 21 points or fewer (shaded region). Alpha = 0.05.
3.3.3 Impact of Education on Overall Radiation Attitudes

3.3.3.1 Descriptive Statistics – Overall Radiation Attitudes

The maximum score for overall radiation attitudes was 100 points, representing a score of five on 20 individual Likert items. The minimum score was 20, representing a score of one on each item. The mean overall radiation attitude score for the control group on the first application of the questionnaire was 69.03 ± 16.26 points. On the second application of the questionnaire, the mean overall radiation attitude score for the control group was 73.94 ± 18.41 points. For the education group, the mean overall radiation attitude score on the first application of the questionnaire was 70.70 ± 15.05 points. Following the education intervention, the mean overall radiation attitude score for the education group on the second application of the questionnaire was 81.28 ± 12.08 points.

Of the participants in the control group, 25 (67%) showed an increase in overall radiation attitude score, 11 (30%) showed a decrease, and one (3%) showed no change. For the education group, 40 participants (93%) showed an increase in overall radiation attitude score, three a decrease (7%), and zero no change.

3.3.3.2 Shapiro-Wilk Test for Normality – Overall Radiation Attitude

The Shapiro-Wilk test for normality was not significant for either the control or education group prior to the intervention (control p = 0.606; education p = 0.162). The test was significant for both groups following the intervention (control p = 0.021; education p = 0.05; Figure 10).
Figure 10 Distribution of Overall Radiation Attitude Scores Before and After Educational Intervention: Distribution of overall radiation attitude scores as measured by a 20 item Likert scale. Maximum score is 100, based on a score value of 5 points per Likert item. Minimum score is 20, based on a score value of 1 point per item. The questionnaire was administered over the phone to 500 participants, of which 80 continued in the research project and whose scores are represented in the results. Continuing participants were separated into 2 groups: a control group and an education group which was administered an educational package on radiation. Participants were subsequently administered the same questionnaire for a second time. (a) distribution of overall radiation attitude scores for the control group on the first administration of the questionnaire (Shapiro-Wilk test for normality not significant, p = 0.606); (b) distribution of overall radiation attitude scores for the education group on the first administration of the questionnaire (Shapiro-Wilk test for normality not significant, p = 0.162); (c) distribution of overall radiation attitude scores for the control group on the second administration of the questionnaire (Shapiro-Wilk test for normality significant, p = 0.021); (d) distribution of overall radiation attitude scores for the education group on the second administration of the questionnaire following the educational intervention (Shapiro-Wilk test for normality significant, p = 0.05).
3.3.3.3 Mixed Model ANOVA – Overall Radiation Attitude

The mixed model ANOVA estimated marginal means plot indicated an interaction (Figure 11) which was statistically significant (p = 0.004). However, Levene’s test for homogeneity of variances was violated for the post-intervention (p = 0.006). Box’s test of equality of covariance was also violated (p < 0.01).

3.3.3.4 T-test – Overall Radiation Attitude

There was no significant difference between the control and education overall radiation attitude pre-intervention scores (Levene’s test p = 0.353; t-test p = 0.635). There was a significant difference between control and education overall radiation attitude post-intervention scores (Levene’s test p = 0.006; Welch’s test p = 0.043).

The control group showed no significant difference in pre-intervention and post-intervention overall radiation attitude scores (Levene’s test p = 0.482; t-test p = 0.227). The education group did show a significant difference in pre-intervention and post-intervention overall radiation attitude scores (Levene’s test = 0.245; t-test p = 0.001).

3.3.3.5 Mann Whitney U Test – Overall Radiation Attitude

The distributions were visually similar for both the control and education overall radiation attitudes prior to the intervention, and the median score was not significantly different (p = 0.585). The distributions were visually similar for the control and education groups post-intervention (Figure 12), and the median score was not significantly different (p = 0.132).
Figure 11 - Estimated Marginal Means of Overall Radiation Attitude Scores: Estimated marginal means plot from a mixed model ANOVA on overall radiation attitude scores on a 20 item Likert scale. The questionnaire was administered over the phone to 500 participants, of which 80 continued in the research project and whose scores are represented in the results. Continuing participants were separated into 2 groups: a control group (n = 37) and an education group (n = 43) which was administered an educational package on radiation. Participants were subsequently administered the same questionnaire for a second time. The interaction between the two treatment groups and the two applications of the questionnaire was significant (p = 0.004). However, Levene’s test for homogeneity of variances was violated for the post-test (p < 0.006). Box’s test of equality of covariance was also violated (p < 0.01). Error bars represent 95% confidence intervals.
Figure 12 – Mann Whitney U Test Distributions for Overall Radiation Attitude Scores Between Control and Education Groups: Mann Whitney U test distribution comparison of overall radiation attitude scores. Scores were based on 20 Likert items within a questionnaire, combined into a single Likert scale. The first questionnaire was administered over the phone to 500 participants, of which 80 continued in the research project and whose scores are represented in the results. Continuing participants were separated into 2 groups: a control group (n = 37) and an education group (n = 43) which was administered an educational package on radiation. Participants subsequently were administered the same questionnaire for a second time. (a) Comparison of distributions between the control and education groups on the first questionnaire. There was no difference in the median overall radiation attitude score (p = 0.585); (b) Comparison of distributions between the control and education groups on the second questionnaire. There was no difference in the median overall radiation attitude score (p = 0.132).
The distributions for the control group pre-intervention and post-intervention were similar and the median score was not significantly different (p = 0.146). The distributions for the education group pre-intervention and post-intervention were visually similar (Figure 13). The difference in median scores was significant (p = 0.001).

3.3.3.6 Gain Score – Overall Radiation Attitude

The mean overall radiation attitude gain score was higher for the education group (10.6 points) than the control group (4.9 points). The difference was statistically significant (Levene’s test p = 0.631; t-test p = 0.004), with the mean gain score for the education group being 5.7 points higher than the control group (95% confidence interval 1.8 – 9.5).

3.3.3.7 ANCOVA Analysis with Johnson-Neyman Procedure – Overall Radiation Attitude

The Johnson-Neyman procedure was used to find the region(s) of significance along overall radiation attitude scores on the first application of the questionnaire for which a significant difference between the control and education treatment groups exists in the overall radiation attitudes on the second application of the questionnaire.

The post-intervention estimated means for the education group were significantly higher than the post-intervention estimated means for the control group when the pre-intervention overall radiation attitude score was 75 points or fewer (with a minimum score of 20 points). The education and control estimated means were not significantly different when the pre-intervention overall radiation attitude score was between 76 and 100 points (with 100 points being the highest possible score; Figure 14).
Figure 13 Mann Whitney U Test Distributions for Overall Radiation Attitude Scores Within Control and Education Groups: Mann Whitney U test distribution comparison of overall radiation attitude scores. Scores were based on 20 Likert items contained within a questionnaire, summed into a single Likert scale. The questionnaire was administered over the phone to 500 participants, of which 80 continued in the research project and whose scores are represented in the results. Continuing participants were separated into 2 groups: a control group (n = 37) and an education group (n = 43) which was administered an educational package on radiation. Participants subsequently were administered the same questionnaire for a second time. (a) Comparison of distributions for the control group between the second (left panel) and first (right panel) administration of the questionnaire. There was no difference in the median overall radiation attitude score (p = 0.146); (b) Comparison of distributions for the education group between the second (left panel) and first (right panel) administration of the questionnaire. The median scores were significantly different (p = 0.001).
Figure 14 Johnson-Neyman Analysis for Overall Radiation Attitude Scores: Johnson-Neyman analysis of the difference between the control and education treatment groups on overall radiation attitude scores. Scores were based on responses to 20 Likert items combined into a single Likert scale ranging from 20 to 100 points. The first questionnaire was administered over the phone to 500 participants, of which 80 continued in the research project and whose scores are represented in the results. Continuing participants were separated into 2 groups: a control group (n = 37) and an education group (n = 43) which was administered an educational package on radiation. Participants subsequently were administered the same questionnaire for a second time. The Johnson-Neyman procedure compares differences between the control and education groups overall radiation attitude scores on the second questionnaire along the spectrum of overall radiation attitude scores on the first questionnaire. Second questionnaire overall radiation attitude scores were significantly higher in the education group when the first questionnaire overall radiation attitude score was 75 points or fewer (shaded region). Alpha = 0.05.
3.3.3.8 Overall Radiation Attitude Summary

The combined results of a mixed model ANOVA, t-tests, Mann Whitney U tests, and gain scores indicated that a significant increase in overall radiation attitudes occurred for the education group as opposed to the control group. The ANCOVA analysis with Johnson-Neyman procedure specified that the significant increase in overall radiation attitude occurred for pre-intervention attitudes scores in the bottom two thirds of initial scores (75 points or fewer).

3.3.4 Impact of Education on Nuclear Power Attitudes

3.3.4.1 Descriptive Statistics – Nuclear Power Attitude

The maximum score on the nuclear power specific portion of the radiation attitude survey was 30, representing a score of five on six individual Likert items. The minimum score was 6, representing a score of 1 on those items. The mean nuclear power attitude score for the control group on the first application of the questionnaire was 18.00 ± 6.91 points. The mean nuclear power attitude score for the control group on the second application of the questionnaire was 19.70 ± 7.75 points. The mean nuclear power attitude score for the education group on the first application of the questionnaire was 20.53 ± 5.90 points. Following the education intervention, the mean nuclear power attitude score for the education group was 23.91 ± 5.85 points.

For control group participants, 19 (51%) showed an increase in nuclear power attitude score between the first and second application of the questionnaire, while 13 (35%) showed a decrease and 5 (14%) no change. For the education group, 33 participants (77%) showed an increase in nuclear power attitude, while 7 (16%) showed a decrease and 3 (7%) showed no change.
### 3.3.4.2 Shapiro-Wilk Test for Normality – Nuclear Power Attitude

The Shapiro-Wilk test for normality was not significant for either the control or education group prior to the intervention (control $p = 0.147$; education $p = 0.206$). The test was significant for both groups following the intervention (control $p = 0.010$; education $p = 0.001$; Figure 15).

### 3.3.4.3 Mixed Model ANOVA – Nuclear Power Attitude

The mixed model ANOVA plot indicated a potential interaction (Figure 16), however the interaction was not statistically significant ($p = 0.079$). Levene’s test for homogeneity was violated for the second questionnaire ($p = 0.027$). Box’s test of equality of covariance was not significant ($p = 0.184$).

### 3.3.4.4 T-test – Nuclear Power Attitudes

There was no significant difference between the control and education nuclear power attitude pre-intervention scores (Levene’s test $p = 0.154$; t-test $p = 0.08$). There was a significant difference between control and education nuclear power attitudes following the intervention (Levene’s test $p = 0.027$; Welch’s test $p = 0.009$).

The control group showed no significant difference in pre-intervention and post-intervention nuclear power attitude scores (Levene’s test $p = 0.418$; t-test $p = 0.332$). The education group did show a significant difference in pre-intervention and post-intervention nuclear power attitude scores (Levene’s test $p = 0.971$; t-test $p = 0.009$).
Figure 15 Distribution of Nuclear Power Attitude Scores Before and After Educational Intervention:
Distribution of nuclear power radiation attitude scores as measured by a six item Likert scale. Maximum score is 30, based on a score value of five points per item. Minimum score is six, based on a score value of one point per item. The questionnaire was administered over the phone to 500 participants, of which 80 continued in the research project and whose scores are represented in the results. Continuing participants were separated into 2 groups: a control group and an education group which was administered an educational package on radiation. Participants were subsequently administered the same questionnaire for a second time. (a) Distribution of nuclear power radiation attitude scores for the control group on the first administration of the questionnaire (Shapiro-Wilk test for normality not significant, p = 0.147); (b) distribution of nuclear power radiation attitude scores for the education group on the first administration of the questionnaire (Shapiro-Wilk test for normality not significant, p = 0.206); (c) distribution of nuclear power radiation attitude scores for the control group on the second administration of the questionnaire (Shapiro-Wilk test for normality significant, p = 0.01); (d) distribution of nuclear power radiation attitude scores for the education group on the second administration of the questionnaire following the educational intervention (Shapiro-Wilk test for normality significant, p = 0.001).
Figure 16 Estimated Marginal Means of Nuclear Power Attitude Scores: Estimated marginal means plot from a mixed model ANOVA on nuclear power radiation attitude scores on a 6 item Likert scale. The questionnaire was administered over the phone to 500 participants, of which 80 continued in the research project and whose scores are represented in the results. Continuing participants were separated into 2 groups: a control group (n = 37) and an education group (n = 43) which was administered an educational package on radiation. Participants were subsequently administered the same questionnaire for a second time. The interaction between the two treatment groups and the two applications of the questionnaire was not significant (p = 0.079). Levene’s test for homogeneity of variances was violated for the second questionnaire (p = 0.027). Box’s test of equality of covariance was not significant (p = 0.184). Error bars represent 95% confidence intervals.
3.3.4.5 Mann Whitney U Test – Nuclear Power Attitude

The distributions were visually similar for the control and education groups prior to the intervention, and the median score was not statistically significant (p = 0.122). The distributions were not similar for the control and education groups following the intervention, and the difference was significant (p = 0.009; Figure 17).

The distributions were visually similar for the control group pre-intervention and post-intervention, and the median score was not statistically significant (p = 0.327). The distributions were not visually similar for the education group pre-intervention and post-intervention, and the difference was statistically significant (p = 0.005; Figure 18).

3.3.4.6 Gain Score – Nuclear Power Attitude

The mean gain score in nuclear power attitudes was higher for the education group (3.4) than the control group (1.7), however the difference was not statistically significant (p = 0.079).

3.3.4.7 ANCOVA with Johnson-Neyman Procedure – Nuclear Power Attitude

The Johnson-Neyman procedure was used to find the region(s) of significance along nuclear power radiation attitude scores on the first application of the questionnaire for which a significant difference between the control and education treatment groups exists in the nuclear power radiation attitudes on the second application of the questionnaire.

The post-intervention estimated means for the education group were significantly higher than the post-intervention estimated means for the control group when the pre-intervention nuclear power attitude score was 16 points or fewer (with a minimum score of 6). The post-intervention education and control estimated means were not significantly different when the pre-intervention nuclear power attitude score was between 17 and 30 points (with 30 points being the highest possible score; Figure 19).
Figure 17 - Mann Whitney U Test Distributions for Nuclear Power Attitude Scores Between Control and Education Groups: Mann Whitney U test distribution comparison of nuclear power radiation attitude scores. Scores were based on 6 Likert items within a questionnaire, combined into a single Likert scale. The first questionnaire was administered over the phone to 500 participants, of which 80 continued in the research project and whose scores are represented in the results. Continuing participants were separated into 2 groups: a control group (n = 37) and an education group (n = 43) which was administered an educational package on radiation. Participants subsequently were administered the same questionnaire for a second time. (a) Comparison of distributions between the control and education groups on the first questionnaire. There was no statistical difference between the distributions (p = 0.122); (b) Comparison of distributions between the control and education groups on the second questionnaire. The distributions were statistically different score (p = 0.009).
Figure 18 Mann Whitney U Test Distributions for Nuclear Power Attitude Scores Within Control and Education Groups: Mann Whitney U test distribution comparison of nuclear power radiation attitude scores. Scores were based on 6 Likert items contained within a questionnaire, summed into a single Likert scale. The questionnaire was administered over the phone to 500 participants, of which 80 continued in the research project and whose scores are represented in the results. Continuing participants were separated into 2 groups: a control group (n = 37) and an education group (n = 43) which was administered an educational package on radiation. Participants subsequently were administered the same questionnaire for a second time. (a) Comparison of distributions for the control group between the second (left panel) and first (right panel) administration of the questionnaire. There was no difference in the median knowledge score (p = 0.327); (b) Comparison of distributions for the education group between the second (left panel) and first (right panel) administration of the questionnaire. The median scores were significantly different (p = 0.005).
Figure 19 Johnson-Neyman Analysis for Nuclear Power Attitude Scores: Johnson-Neyman analysis of the difference between the control and education treatment groups on nuclear power radiation attitude scores. Scores were based on responses to 6 Likert items combined into a single Likert scale ranging from 6 to 30 points. The first questionnaire was administered over the phone to 500 participants, of which 80 continued in the research project and whose scores are represented in the results. Continuing participants were separated into 2 groups: a control group (n = 37) and an education group (n = 43) which was administered an educational package on radiation. Participants subsequently were administered the same questionnaire for a second time. The Johnson-Neyman procedure compares differences between the control and education groups nuclear power radiation attitude scores on the second questionnaire along the spectrum of nuclear power radiation attitude scores on the first questionnaire. Second questionnaire nuclear power radiation attitude scores were significantly higher for the education group when the first questionnaire nuclear power radiation attitude score was 16 points or fewer (shaded region). Alpha = 0.05.
3.3.4.8 Nuclear Power Attitude Summary

The combined results of a mixed model ANOVA, t-tests, Mann Whitney U tests, and gain scores provided mixed evidence towards a significant increase in nuclear power attitude scores in the education group as compared to the control group. However, the ANCOVA analysis with Johnson-Neyman procedure suggests that a significant increase for education scores as compared to the control does occur for pre-intervention nuclear power attitudes in the bottom 40 percent of initial scores (17 points or fewer on the Likert scale).

3.3.5 Impact of Education on Medical Radiation Attitudes

3.3.5.1 Descriptive Statistics – Medical Radiation Attitude

The maximum score on the medicine specific portion of the radiation attitude questionnaire was 30 points, representing a score of five on six individual Likert items. The minimum score was six, representing a score of one on the six items. The mean medical radiation attitude score for the control group was 23.81 ± 4.86 points on the first application of the questionnaire. On the second application of the questionnaire, the mean medical radiation attitude score for the control group was 25.35 ± 5.10 points. For the education group, the mean medical radiation attitude score on the first application of the questionnaire was 22.97 ± 4.90 points. This shifted to a mean score of 25.23 ± 3.70 points following the education intervention.

Of the control group participants, 17 (46%) showed an increase in medical radiation attitudes, 11 (30%) showed a decrease, and 9 (24%) showed no change. Of the education group participants, 26 (60%) showed an increase in medical radiation attitudes, 10 (23%) showed a decrease, and 7 (16%) showed no change.
3.3.5.2 Shapiro-Wilk Test for Normality – Medical Radiation Attitude

The Shapiro-Wilk test for normality was not significant for the control group prior to the intervention (p = 0.059). It was significant for the education group prior to the intervention (p = 0.009) and for both the control group and the education group following the intervention (control p < 0.0005; education p = 0.021; Figure 20)

3.3.5.3 Mixed Model ANOVA – Medical Radiation Attitude

The mixed model ANOVA plot indicated a potential interaction (Figure 21), however it was not statistically significant (p = 0.389). Both Levene’s test for homogeneity of variances (pre-intervention p = 0.626; post-intervention p = 0.244) and Box’s test of equality of covariance (p = 0.057) were not significant.

3.3.5.4 T-Test – Medical Radiation Attitude

There was no significant difference between the control and education group pre-intervention (Levene’s test p = 0.626; t-test p = 0.448) or post-intervention (Levene’s test p = 0.244; t-test p = 0.905). The control group showed no significant difference in medical radiation attitude scores pre-intervention and post-intervention (Levene’s test p = 0.744; p = 0.188), while the education group did show a significant difference in medical radiation attitude scores pre-intervention and post-intervention (Levene’s test p = 0.280; p = 0.018).
Figure 20 Distribution of Medical Radiation Attitude Scores Before and After Educational Intervention:

Distribution of medical radiation attitude scores as measured by a six item Likert scale. Maximum score is 30, based on a score of five points on each individual Likert item. Minimum score is six, based on a score value of one point per item. The questionnaire was administered over the phone to 500 participants, of which 80 continued in the research project and whose scores are represented in the results. Continuing participants were separated into two groups: a control group (n = 37) and an education group (n = 43) which was administered an educational package on radiation. Participants were subsequently administered the same questionnaire for a second time. (a) Distribution of medical radiation attitude scores for the control group on the first administration of the questionnaire (Shapiro-Wilk test for normality not significant, p = 0.059); (b) distribution of medical radiation attitude scores for the education group on the first administration of the questionnaire (Shapiro-Wilk test for normality significant, p = 0.009); (c) distribution of medical radiation attitude scores for the control group on the second administration of the questionnaire (Shapiro-Wilk test for normality significant, p = <0.0005); (d) distribution of medical radiation attitude scores for the education group on the second administration of the questionnaire following the educational intervention (Shapiro-Wilk test for normality significant, p = 0.021).
Figure 21 Estimated Marginal Means of Medical Radiation Attitude Scores: Estimated marginal means plot from a mixed model ANOVA on medical radiation attitude scores on a six item Likert scale. The questionnaire was administered over the phone to 500 participants, of which 80 continued in the research project and whose scores are represented in the results. Continuing participants were separated into two groups: a control group (n = 37) and an education group (n = 43) which was administered an educational package on radiation. Participants were subsequently administered the same questionnaire for a second time. The interaction between the two treatment groups and the two applications of the questionnaire was not significant (p = 0.389). Levene’s test for homogeneity of variances was not significant for the first or second administration of the questionnaire (p = 0.626; p = 0.244). Box’s test of equality of covariance was not significant (p = 0.057). Error bars represent 95% confidence intervals.
3.3.5.5 Mann Whitney U Test – Medical Radiation Attitude

The distribution of medical radiation attitude scores was visually similar for the education and control groups both pre-intervention and post-intervention (Figure 22), and the median scores were not significantly different for either scenario (pre-intervention \( p = 0.471 \); post-intervention \( p = 0.356 \)).

The distributions of medical radiation attitude scores were visually similar for the control group pre-intervention and post-intervention, and no significant difference in median value was present \( (p = 0.356) \). While the distributions of medical radiation attitudes scores were similar for the education group pre-intervention and post-intervention, a significant difference in median score was present \( (p = 0.029; \text{Figure 23}) \).

3.3.5.6 Gain Score – Medical Radiation Attitude

The mean gain score in medical radiation attitudes was 2.26 points for the education group and 1.54 for the control group. The difference was not statistically significant \( (\text{Levene’s test } p = 0.440; \text{t-test } p = 0.389) \).

3.3.5.7 ANCOVA with Johnson-Neyman Procedure – Medical Radiation Attitude

The Johnson-Neyman procedure was used to find the region(s) of significance along medical radiation attitude scores on the first application of the questionnaire for which a significant difference between the control and education treatment groups exists in the medical radiation attitudes on the second application of the questionnaire.

The post-intervention estimated means for the education group were significantly higher than the post-intervention estimated means for the control group when the pre-intervention medical radiation attitude score was 20 points or fewer. The education and control estimated means were not significantly different when the pre-intervention medical radiation attitude score was between 21 and 29 points.
Figure 22 Mann Whitney U Test Distributions for Medical Radiation Attitude Scores Between Control and Education Groups: Mann Whitney U test distribution comparison of medical radiation attitude scores. Scores were based on six Likert items within a questionnaire, combined into a single Likert scale. The maximum score was 30, representing a score of five on each individual Likert item, and the minimum score six representing a score of one on each item. The first questionnaire was administered over the phone to 500 participants, of which 80 continued in the research project and whose scores are represented in the results. Continuing participants were separated into two groups: a control group (n = 37) and an education group (n = 43) which was administered an educational package on radiation. Participants subsequently were administered the same questionnaire for a second time. (a) Comparison of distributions between the control and education groups on the first questionnaire. There was no statistical difference between the distributions (p = 0.471); (b) Comparison of distributions between the control and education groups on the second questionnaire. The distributions were not statistically different (p = 0.356).
Figure 23 Mann Whitney U Test Distributions for Medical Radiation Attitude Scores Within Control and Education Groups: Mann Whitney U test distribution comparison of medical radiation attitude scores. Scores were based on six Likert items within a questionnaire, combined into a single Likert scale. The maximum score was 30, representing a score of five on each individual Likert item, and the minimum score six representing a score of one on each item. The questionnaire was administered over the phone to 500 participants, of which 80 continued in the research project and whose scores are represented in the results. Continuing participants were separated into two groups: a control group (n = 37) and an education group (n = 43) which was administered an educational package on radiation. Participants subsequently were administered the same questionnaire for a second time. (a) Comparison of distributions for the control group between the second (left panel) and first (right panel) administration of the questionnaire. There was no difference in the median knowledge score (p = 0.356); (b) Comparison of distributions for the education group between the second (left panel) and first (right panel) administration of the questionnaire. The median scores were significantly different (p = 0.029).
The post-intervention estimated means for the control group were significantly higher than the post-intervention estimated means for the education group when the pre-test score was 30 points (Figure 24).

3.3.5.8 Medical Radiation Attitude Summary

The combined results of a mixed model ANOVA, t-tests, Mann Whitney U tests, and gain scores provided limited evidence towards a significant increase in medical radiation attitude scores in the education group as compared to the control group. However, the ANCOVA analysis with Johnson-Neyman procedure suggests that a significant increase for education scores as compared to the control does occur for pre-intervention medical radiation attitudes in the bottom 60 percent of initial scores (20 points or fewer). It also suggests that for extremely high initial scores (30 points), the intervention had a negative impact and reduced medical radiation scores.

3.3.6 Impact of Education on Societal Approach to Radiation Attitude

3.3.6.1 Descriptive Statistics – Societal Approach to Radiation Attitude

The maximum score on the societal approach to radiation attitude portion of the questionnaire was 25, representing a score of five on five individual Likert items. The minimum score was five, representing a score of one on those items. For the control group, the mean societal approach to radiation attitude score was 17.41 ± 3.95 points on the first application of the questionnaire. The mean score following the second application of the questionnaire was 17.64 ± 4.44 points. For the education group, the mean societal approach to radiation attitude score was 17.07 ± 4.02 points on the first application of the questionnaire. After the education intervention, the mean score was 19.26 ± 3.37 points.
Figure 24 Johnson-Neyman Analysis for Medical Radiation Attitude Scores: Johnson-Neyman analysis of the difference between the control and education treatment groups on medical radiation attitude scores. Scores were based on responses to six Likert items combined into a single Likert scale ranging from six to 30 points. The first questionnaire was administered over the phone to 500 participants, of which 80 continued on in the research project and whose scores are represented in the results. Continuing participants were separated into two groups: a control group (n = 37) and an education group (n = 43) which was administered an educational package on radiation. Participants subsequently were administered the same questionnaire for a second time. The Johnson-Neyman procedure compares differences between the control and education groups medical radiation attitude scores on the second questionnaire along the spectrum of medical radiation attitude scores on the first questionnaire. Second questionnaire medical radiation attitude scores were significantly higher for the education group when the first questionnaire medical radiation attitude score was 20 points or fewer (shaded region). Second questionnaire medical radiation attitude scores were significantly higher for the control group when the first questionnaire medical radiation attitude score was 30 points (striated bar). Alpha = 0.05.
For the control group participants, 18 (48%) showed an increase in society radiation attitude scores, 14 (38%) showed a decrease, and 5 (14%) showed no change. For the education group, 25 participants (58%) showed an increase in society radiation attitude scores, 8 (19%) showed a decrease, and 10 (23%) showed no change.

### 3.3.6.2 Shapiro-Wilk Test for Normality – Societal Approach to Radiation

The Shapiro-Wilk test for normality was not significant for the control group or the education group pre-intervention (control p = 0.400; education p = 0.204). The test was also not significant for the education group post-intervention (p = 0.504), but was significant for the control group post-intervention (p = 0.012; Figure 25).

### 3.3.6.3 Mixed Model ANOVA – Societal Approach to Radiation Attitude

The mixed model ANOVA plot indicated an interaction (Figure 26), which was significant (p = 0.010). Levene’s test for homogeneity of variances was not significant (pre-intervention p = 0.802; post-intervention p = 0.184). Box’s test for equality of covariance was also not significant (p = 0.252).

### 3.3.6.4 T-Test – Societal Approach to Radiation Attitude

There was no significant difference between the education and control groups pre-intervention (Levene’s test p = 0.802; t-test p = 0.709) or post-intervention (Levene’s test p = 0.184; t-test p = 0.070).

The control group societal approach to radiation scores were not significantly different pre-intervention and post-intervention (Levene’s test p = 0.667; t-test p = 0.804). The education group was significantly different pre-intervention and post-intervention (Levene’s test p = 0.971; t-test p = 0.009).
Figure 25 Distribution of Societal Approach to Radiation Attitude Scores Before and After Educational Intervention: Distribution of societal approach to radiation attitude scores as measured by a six item Likert scale. Maximum score is 25, based on a score of five points per individual Likert item. Minimum score is five, based on a score of one point per item. The questionnaire was administered over the phone to 500 participants, of which 80 continued in the research project and whose scores are represented in the results. Continuing participants were separated into two groups: a control group (n = 37) and an education group (n = 43) which was administered an educational package on radiation. Participants were subsequently administered the same questionnaire for a second time. (a) Distribution of societal approach to radiation attitude scores for the control group on the first administration of the questionnaire (Shapiro-Wilk test for normality not significant, p = 0.400); (b) distribution of societal approach to radiation attitude scores for the education group on the first administration of the questionnaire (Shapiro-Wilk test for normality significant, p = 0.204); (c) distribution of societal approach to radiation attitude scores for the control group on the second administration of the questionnaire (Shapiro-Wilk test for normality significant, p = 0.012); (d) distribution of societal approach to radiation attitude scores for the education group on the second administration of the questionnaire following the educational intervention (Shapiro-Wilk test for normality not significant, p = 0.504).
Figure 26 Estimated Marginal Means of Societal Approach to Radiation Attitude Scores: Estimated marginal means plot from a mixed model ANOVA on societal approach to radiation attitude scores on a five item Likert scale. The questionnaire was administered over the phone to 500 participants, of which 80 continued in the research project and whose scores are represented in the results. Continuing participants were separated into two groups: a control group (n = 37) and an education group (n = 43) which was administered an educational package on radiation. Participants were subsequently administered the same questionnaire for a second time. The interaction between the two treatment groups and the two applications of the questionnaire was significant (p = 0.010). Levene’s test for homogeneity of variances was not significant for the first or second administration of the questionnaire (p = 0.802; p = 0.184). Box’s test of equality of covariance was not significant (p = 0.252). Error bars represent 95% confidence intervals.
3.3.6.5 Mann Whitney U Test – Societal Approach to Radiation Attitude

The distribution of societal approach to radiation attitude scores was visually similar between the control and education groups both pre-intervention and post-intervention (Figure 27). The median scores were not significantly different in either the pre-intervention or post-intervention scenarios (pre-intervention $p = 0.702$; post-intervention $p = 0.188$).

The distributions for the control societal approach to radiation attitudes were visually similar pre-intervention and post-intervention, and the median score was not significantly different ($p = 0.599$). The distributions were also visually similar for the education group pre-intervention and post-intervention (Figure 28), however the median score was significantly different ($p = 0.016$).

3.3.6.6 Gain Score – Societal Approach to Radiation Attitude

The mean gain score in societal approach to radiation attitudes was 2.19 points for the education group and 0.24 points for the control group. This difference was significant (Levene’s test $p = 0.878$; t-test $p = 0.010$), with the mean gain score for the education group being 1.94 points higher than for the control group (95% confidence interval 0.49 – 3.40 points).

3.3.6.7 ANCOVA with Johnson-Neyman Procedure – Societal Approach to Radiation Attitude

The Johnson-Neyman procedure was used to find the region(s) of significance along societal approach to radiation attitude scores on the first application of the questionnaire for which a significant difference between the control and education treatment groups exists in the societal approach to radiation attitudes on the second application of the questionnaire.
Figure 27 Mann Whitney U Test Distributions for Societal Approach to Radiation Attitude Scores Between Control and Education Groups: Mann Whitney U test distribution comparison of societal approach to radiation attitude scores. Scores were based on five Likert items within a questionnaire, combined into a single Likert scale. Possible scores ranged from five to 25 points. The first questionnaire was administered over the phone to 500 participants, of which 80 continued in the research project and whose scores are represented in the results. Continuing participants were separated into two groups: a control group (n = 37) and an education group (n = 43) which was administered an educational package on radiation. Participants subsequently were administered the same questionnaire for a second time. (a) Comparison of distributions between the control and education groups on the first questionnaire. There was no statistical difference between the distributions (p = 0.702); (b) Comparison of distributions between the control and education groups on the second questionnaire. The distributions were not statistically different score (p = 0.188).
Figure 28 Mann Whitney U Test Distributions for Societal Approach to Radiation Attitude Scores Within Control and Education Groups: Mann Whitney U test distribution comparison of societal approach to radiation attitude scores. Scores were based on five Likert items contained within a questionnaire, summed into a single Likert scale. Possible scores ranged from five to 25 points. The questionnaire was administered over the phone to 500 participants, of which 80 continued in the research project and whose scores are represented in the results. Continuing participants were separated into two groups: a control group (n = 37) and an education group (n = 43) which was administered an educational package on radiation. Participants subsequently were administered the same questionnaire for a second time. (a) Comparison of distributions for the control group between the second (left panel) and first (right panel) administration of the questionnaire. There was no difference in the median knowledge score (p = 0.599); (b) Comparison of distributions for the education group between the second (left panel) and first (right panel) administration of the questionnaire. The median scores were significantly different (p = 0.016).
The post-intervention estimated means for the education group were significantly higher than the post-intervention estimated means for the control group when the pre-intervention societal approach to radiation attitude score was 17 points or fewer (with a minimum score of five).

The education and control estimated means were not significantly different when the pre-intervention societal approach to radiation attitude score was between 18 and 25 points, with 25 points being the highest possible score (Figure 29).

3.3.6.8 Societal Approach to Radiation Attitude Summary

The combined results of a mixed model ANOVA, t-tests, Mann Whitney U tests, and gain scores indicated a significant increase in societal approach to radiation attitude scores in the education group as compared to the control group. The ANCOVA analysis with Johnson-Neyman procedure suggested that a significant increase for education scores as compared to the control occurs for pre-intervention societal approach to radiation attitudes in the bottom 60 percent of initial scores (17 points or fewer).
Figure 29 Johnson-Neyman Analysis for Societal Approach to Radiation Attitude Scores: Johnson-Neyman analysis of the difference between the control and education treatment groups on societal approach to radiation attitude scores. Scores were based on responses to five Likert items combined into a single Likert scale ranging from five to 25 points. The first questionnaire was administered over the phone to 500 participants, of which 80 continued in the research project and whose scores are represented in the results. Continuing participants were separated into two groups: a control group (n = 37) and an education group (n = 43) which was administered an educational package on radiation. Participants subsequently were administered the same questionnaire for a second time. The Johnson-Neyman procedure compares differences between the control and education groups societal approach to radiation attitude scores on the second questionnaire along the spectrum of societal approach to radiation attitude scores on the first questionnaire. Second questionnaire societal approach to radiation attitude scores were significantly higher for the education group when the first questionnaire societal approach to radiation attitude score was 17 points or fewer (shaded region). Alpha = 0.05.
### 3.3.7 Summary Table of Knowledge and Attitude Change

**Table 3: Summary of Knowledge and Attitude Change Following Education Intervention – Knowledge, Overall Radiation Attitudes, and Nuclear Power Radiation Attitudes**

<table>
<thead>
<tr>
<th></th>
<th>Mixed Model ANOVA</th>
<th>T-Tests</th>
<th>Mann Whitney U Test</th>
<th>Gain Score</th>
<th>ANCOVA with Johnson Neyman</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge</td>
<td>p &lt; 0.0005</td>
<td>Between Subjects: Pre-test p = 0.864 Post-test p &lt; 0.0005</td>
<td>Between Subjects: Pre-test p = 0.850 Post-test p &lt; 0.0005</td>
<td>p &lt; 0.0005</td>
<td>Education significantly higher than control when pre-test scores were 21 points or fewer</td>
</tr>
<tr>
<td></td>
<td>Levene's test p &lt; 0.0005</td>
<td>Within Subjects: Control p = 0.834 Education p &lt; 0.0005</td>
<td>Within Subjects: Control p = 0.400 Education p &lt; 0.0005</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Box’s test p &lt; 0.0005</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall attitudes</td>
<td>p = 0.004</td>
<td>Between Subjects: Pre-test p = 0.353 Post-test p = 0.043</td>
<td>Between Subjects: Pre-test p = 0.585 Post-test p = 0.132</td>
<td>p = 0.004</td>
<td>Education significantly higher than control when pre-test scores were 75 points or fewer.</td>
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<tr>
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<td>Levene’s test p = 0.0006</td>
<td>Within Subjects: Control p = 0.227 Education p = 0.001</td>
<td>Within Subjects: Control p = 0.146 Education p = 0.001</td>
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<tr>
<td></td>
<td>Box’s test p &lt; 0.01</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Nuclear Power Attitudes</td>
<td>p = 0.079</td>
<td>Between Subjects: Pre-test p = 0.154 Post-test p = 0.009</td>
<td>Between Subjects: Pre-test p = 0.122 Post-test p = 0.009</td>
<td>p = 0.079</td>
<td>Education significantly higher than control when pre-test scores were 16 points or fewer.</td>
</tr>
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<td>Levene’s test p = 0.027</td>
<td>Within Subjects: Control p = 0.332 Education p = 0.009</td>
<td>Within Subjects: Control p = 0.327 Education p = 0.005</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Box’s test p = 0.184</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Mixed Model ANOVA</td>
<td>T-Tests</td>
<td>Mann Whitney U Test</td>
<td>Gain Score</td>
<td>ANCOVA with Johnson Neyman</td>
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<td>---------------------------</td>
</tr>
<tr>
<td><strong>Medical Radiation Attitudes</strong></td>
<td>p = 0.389</td>
<td></td>
<td>Between Subjects: Pre-test p = 0.626</td>
<td>Between Subjects: Pre-test p = 0.471</td>
<td>p = 0.389 Education significantly higher than control when pre-test scores were 20 points or fewer.</td>
</tr>
<tr>
<td></td>
<td>Levene’s test p = 0.626</td>
<td></td>
<td>Post-test p = 0.905</td>
<td>Post-test p = 0.356</td>
<td>Control significantly higher than education when pre-test scores were 30 points.</td>
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<tr>
<td></td>
<td>Box’s test p = 0.057</td>
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<td>Within Subjects: Control p = 0.188</td>
<td>Within Subjects: Control p = 0.356</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Education p = 0.018</td>
<td>Education p = 0.029</td>
<td></td>
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<tr>
<td><strong>Societal Approach to Radiation Attitudes</strong></td>
<td>p = 0.010</td>
<td></td>
<td>Between Subjects: Pre-test p = 0.709</td>
<td>Between Subjects: Pre-test p = 0.702</td>
<td>p = 0.010 Education significantly higher than control when pre-test scores were 17 points or fewer.</td>
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<tr>
<td></td>
<td>Levene’s test p = 0.802</td>
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<td>Post-test p = 0.070</td>
<td>Post-test p = 0.188</td>
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</tr>
<tr>
<td></td>
<td>Box’s test p = 0.252</td>
<td></td>
<td>Within Subjects: Control p = 0.804</td>
<td>Within Subjects: Control p = 0.599</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Education p = 0.009</td>
<td>Education p = 0.016</td>
<td></td>
</tr>
</tbody>
</table>
3.3.8 Influence of Knowledge Gain on Radiation Attitude Change

While it has been demonstrated that the educational intervention led to higher knowledge scores as well as a more favourable attitude towards radiation, it remains an outstanding question as to whether it was the change in knowledge that was driving the change in attitudes. To assess this question, Pearson’s correlation was used to assess the correlation between the change in knowledge and change in attitudes in the control and education groups.

Pearson’s correlation between change in knowledge scores and change in attitude scores was not significant for all four attitude categories (overall radiation attitudes, nuclear power radiation attitudes, medical radiation attitudes, and societal approach to radiation attitudes) for the control group. For the education group, significant correlations were observed between change in knowledge and change in overall radiation attitudes and nuclear power radiation attitudes at the .05 level of significance, and for societal approaches to radiation at the 0.1 level of significance (Table 5).

3.3.9 Risk Rating of Sources of Radiation

Participants were queried on their personal assessment of the risk associated with 12 sources of radiation. The sources of radiation were: nuclear waste, nuclear power plants, radon gas, nuclear medicine, cosmic radiation, x-rays, background radiation, taking an airplane flight, smoke detectors, nuclear weapons, CT scans, and naturally occurring radiation found in food. Participants that did not provide a response on either the first or second questionnaire for a particular source of radiation were not included in the analysis for that source. Application of Little’s MCAR test was not significant (p = 0.081), indicating that deletion of those participants rather than replacement data with missing value analysis is acceptable.
Table 5: Pearson correlation matrix of change in radiation attitudes and change in knowledge scores following educational intervention

<table>
<thead>
<tr>
<th></th>
<th>Overall Radiation Attitudes</th>
<th>Nuclear Power Radiation Attitudes</th>
<th>Medical Radiation Attitudes</th>
<th>Societal Approach to Radiation Attitudes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Education</strong></td>
<td>0.404 (p = 0.007)</td>
<td>0.329 (p = 0.031)</td>
<td>0.235 (p = 0.130)</td>
<td>0.282 (p = 0.067)</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td>-0.067 (p = 0.695)</td>
<td>-0.162 (p = 0.337)</td>
<td>0.020 (p = 0.905)</td>
<td>0.092 (p = 0.590)</td>
</tr>
</tbody>
</table>
Mann Whitney U tests were used to assess the change in risk perception of the sources of radiation for the education and control groups. The pre-intervention and post-intervention distributions were visually similar for each of the 12 sources of radiation in the control group (Figure 30). No significant differences in the median risk assessment were observed for any of the 12 sources of radiation in the control group. For the education group, distribution of risk assessment pre-intervention and post-intervention were found to be significantly different for nuclear power plants ($p = 0.003$), cosmic radiation ($p = 0.049$), and naturally occurring radiation found in food ($p = 0.002$), with fewer participants rating these sources of radiation a high or medium risk, and more participants rating them as no or low risk following the intervention (Figure 31). For the remaining nine sources of radiation, no significant difference was observed in the education group following the intervention.

Mann Whitney U tests were also used to compare the control and education groups pre-intervention (Figure 32) and post-intervention (Figure 33). A significant difference was observed between the control and education groups risk assessment scores pre-intervention for nuclear waste ($p = 0.037$) and smoke detectors ($p = 0.050$). Due to these initial differences, no assessment was made on post-intervention scores between the control and education groups for these two sources of radiation. Differences between the control and education group risk assessment distributions were observed for six sources of radiation: nuclear power plants ($p = 0.001$), radon gas ($p = 0.041$), cosmic radiation ($p = 0.029$), background radiation ($p = 0.040$), nuclear weapons ($p = 0.032$), and CT scans ($p = 0.008$).
Figure 30 Radiation Source Risk Assessment Control Group: Risk assessment of 12 sources of radiation by the control group. Participants were asked to rate the risk of each source of radiation as either “no risk” (scored as one point), “low risk” (two points), “medium risk” (three points), or “high risk” (four points). The first questionnaire was administered over the phone to 500 participants, of which 80 (n = 37 for the control group) continued on in the research project and whose scores are represented in the results. The control group was subsequently administered the questionnaire a second time. Radiation sources were: (a) nuclear waste; (b) nuclear power plants; (c) radon gas; (d) nuclear medicine procedures; (e) cosmic radiation; (f) x-rays; (g) background radiation; (h) an airplane flight; (i) smoke detectors; (j) nuclear weapons; (k) CT scans; (l) radiation ingested from food. No sources were significantly different between the first and second administration of the questionnaire.
Figure 31 Radiation Source Risk Assessment Education Group: Risk assessment of 12 sources of radiation by the education group. Participants were asked to rate the risk of each source of radiation as either “no risk” (scored as one point), “low risk” (two points), “medium risk” (three points), or “high risk” (four points). The first questionnaire was administered over the phone to 500 participants, of which 80 (n = 43 for the education group) continued on in the research project and whose scores are represented in the results. The education group was subsequently administered an education packet on radiation and the questionnaire a second time. Radiation sources were (significant results in brackets): (a) nuclear waste; (b) nuclear power plants (p = 0.003); (c) radon gas; (d) nuclear medicine procedures; (e) cosmic radiation (p = 0.049); (f) x-rays; (g) background radiation; (h) an airplane flight; (i) smoke detectors; (j) nuclear weapons; (k) CT scans; (l) radiation ingested from food (p = 0.002).
Figure 32 Radiation Source Risk Assessment Control vs. Education Pre-Intervention: Risk assessment of 12 sources of radiation. Participants were asked to rate the risk of each source of radiation as either “no risk” (scored as one point), “low risk” (two points), “medium risk” (three points), or “high risk” (four points). The first questionnaire was administered over the phone to 500 participants, of which 80 (n = 37 for the control group; n = 43 for the education group) continued on in the research project and whose scores are represented in the results. Radiation sources were (significant results in brackets): (a) nuclear waste (p = 0.037); (b) nuclear power plants; (c) radon gas; (d) nuclear medicine procedures; (e) cosmic radiation; (f) x-rays; (g) background radiation; (h) an airplane flight; (i) smoke detectors (p = 0.05); (j) nuclear weapons; (k) CT scans; (l) radiation ingested from food.
Figure 33 Radiation Source Risk Assessment Control vs. Education Post-Intervention: Risk assessment of 12 sources of radiation. Participants were asked to rate the risk of each source of radiation as either "no risk" (scored as one point), "low risk" (two points), "medium risk" (three points), or "high risk" (four points). The first questionnaire was administered over the phone to 500 participants, of which 80 (n = 37 for the control group; n = 43 for the education group) continued on in the research project and whose scores are represented in the results. The education group was provided with an education package on radiation, and both groups were subsequently administered the questionnaire a second time. As nuclear waste and smoke detectors were significantly different between the two groups pre-intervention, no assessment was made on these sources of radiation post-intervention. Radiation sources were (significant results in brackets): (a) nuclear waste; (b) nuclear power plants (p = 0.001); (c) radon gas (p = 0.041); (d) nuclear medicine procedures; (e) cosmic radiation (p = 0.029); (f) x-rays; (g) background radiation (p = 0.040); (h) an airplane flight; (i) smoke detectors; (j) nuclear weapons (p = 0.032); (k) CT scans (p = 0.008); (l) radiation ingested from food.
For nuclear power plants, cosmic radiation, background radiation, and nuclear weapons, fewer participants rated the risk as high or medium risk, and more as low or no risk, in the education group as compared to the control group following the intervention. For radon gas, while the education group had fewer incidences of high or medium risk, it also had fewer incidences of no risk when compared to the control group. For CT scans, the education group had more frequent responses of high or medium risk, and fewer responses of no or low risk, compared to the control group following the intervention.

3.3.10 Assessment of Use of Radiation in Particular Contexts

Participants were queried on their assessment of whether radiation should be used in six particular contexts: medicine, electricity generation, industry, scientific research, sterilizing medical tools, and decontaminating food. Mann Whitney U tests were used to assess the change in attitude towards use of radiation in particular contexts.

In the control group, the distributions of assessment remained visually similar pre-intervention and post-intervention (Figure 34), with no significant differences in median values observed. For the education group, significantly different distributions pre-intervention and post-intervention were observed for scientific research (0.001), medical procedures (0.041), sterilizing medical tools (0.01), and decontaminating food (0.013). For these uses of radiation, more participants were likely to strongly agree or somewhat agree with their use and fewer participants to disagree or strongly disagree with their use following the educational intervention (Figure 35).
Figure 34 Use of Radiation Control Group: Assessment of six uses of radiation. Participants were asked to determine if they “strongly agreed” (scored as one point), “somewhat agreed” (two points), “neither agreed nor disagreed” (three points), “somewhat disagreed” (four points), or “strongly disagreed” (five points) with a particular use of radiation. The first questionnaire was administered over the phone to 500 participants, of which 80 (n = 37 for the control group) continued on in the research project and whose scores are represented in the results. The control group was subsequently administered the questionnaire a second time. Uses of radiation were: (a) medical procedures; (b) electricity generation; (c) industrial applications; (d) scientific research; (e) sterilizing medical tools; (f) decontaminating food. No sources were significantly different between the first and second administration of the questionnaire.
Figure 35 Use of Radiation Education Group: Assessment of six uses of radiation. Participants were asked to determine if they “strongly agreed” (scored as one point), “somewhat agreed” (two points), “neither agreed nor disagreed” (three points), “somewhat disagreed” (four points), or “strongly disagreed” with a particular use of radiation. The first questionnaire was administered over the phone to 500 participants, of which 80 (n = 43 for the education group) continued on in the research project and whose scores are represented in the results. The education group was subsequently administered an education packet on radiation and the questionnaire a second time (significant results in brackets). Uses of radiation were: (a) medical procedures (p = 0.041); (b) electricity generation; (c) industrial applications; (d) scientific research (p = 0.001); (e) sterilizing medical tools (p = 0.01); (f) decontaminating food (p = 0.013).
Mann Whitney U tests were also used to assess differences between the control and education groups pre-intervention and post-intervention. No differences in distribution of responses were found for any of the six categories prior to the intervention (Figure 36). Following the intervention, a significantly dissimilar distribution was found between the control and education groups on the use of radiation to decontaminate food ($p = .006$). Education participants were more likely to strongly or somewhat agree and less likely to strongly or somewhat disagree to the use of radiation for this purpose (Figure 37).
Figure 36 Use of Radiation Control vs. Education Pre-Intervention: Assessment of six uses of radiation. Participants were asked to determine if they “strongly agreed” (scored as one point), “somewhat agreed” (two points), “neither agreed nor disagreed” (three points), “somewhat disagreed” (four points), or “strongly disagreed” (five points) with a particular use of radiation. The first questionnaire was administered over the phone to 500 participants, of which 80 (n = 37 for the control group; n = 43 for the education group) continued on in the research project and whose scores are represented in the results. Uses of radiation were: (a) medical procedures; (b) electricity generation; (c) industrial applications; (d) scientific research; (e) sterilizing medical tools; (f) decontaminating food. There was no significant difference between the control and education groups on any of the six uses of radiation prior to the educational intervention.
Figure 37 Use of Radiation Control vs. Education Post-Intervention: Assessment of six uses of radiation. Participants were asked to determine if they "strongly agreed" (scored as one point), "somewhat agreed" (two points), "neither agreed nor disagreed" (three points), "somewhat disagreed" (four points), or "strongly disagreed" (five points) with a particular use of radiation. The first questionnaire was administered over the phone to 500 participants, of which 80 (n = 37 for the control group; n = 43 for the education group) continued on in the research project and whose scores are represented in the results. The education group was provided with an education package on radiation, and both groups were subsequently administered the questionnaire a second time. Uses of radiation were (significant results in brackets): (a) medical procedures; (b) electricity generation; (c) industrial applications; (d) scientific research; (e) sterilizing medical tools; (f) decontaminating food (p = 0.006).
3.4 Discussion

In order to assess the accuracy of the information deficit model, a controlled experimental methodology was used to observe the influence that an educational intervention on radiation may have on subsequent radiation knowledge and attitudes. The inclusion of a control group allowed for the differences in the education group pre-intervention and post-intervention to be analyzed in a statistically robust fashion.

In order to assess whether increases in knowledge about radiation can have a subsequent impact on radiation attitudes, an increase in radiation knowledge among participants in the education group (which is greater than any such increase seen in the control group) needed to first be established. The efficacy of the education materials in conveying knowledge about radiation to the participants was confirmed via analysis of the difference in knowledge scores between the control and education groups’ pre-intervention and post-intervention. Regardless of the method of analysis, a difference in knowledge scores was demonstrated between the education and control treatment groups after the education group had undergone the educational intervention. As there was a maximum possible score, which some participants were near to or had achieved prior to the intervention, the significant difference between the control and education groups was only present when the pre-intervention knowledge score was 21 points or fewer (out of a maximum score of 23 points). The ability of the educational materials to convey an increased understanding of radiation to the participants (at least to the extent to which radiation knowledge was measured by the questionnaire) was confirmed.

Taken as a whole of the statistical analysis methods applied to the collected data, it was determined that the educational treatment group did undergo a significant change in radiation attitudes as compared to the control group, at least when assessing overall radiation attitudes, nuclear power radiation attitudes, and societal approaches to radiation attitudes. The Johnson Neyman procedure allowed for a nuanced
understanding of the impact of the intervention on radiation attitudes. Participants who already had a relatively favourable attitude towards these three aspects of radiation attitudes were unchanged by the educational intervention, with no difference observed between the education and control groups. However, for those who began with a lower attitude, the educational intervention significantly increased radiation attitudes as compared to the control group.

The application of a more favourable attitude towards radiation amongst members of the education group was observed in assessments made towards the use and risks of radiation. The education group became significantly more open to use of radiation for the purposes of scientific research, sterilizing medical tools, and decontaminating food, whereas no such change was observed for the control group. In terms of radiation risk assessment, the increase in attitude towards radiation was reflected in the education group lowering its risk rating for nuclear power plants, cosmic radiation, and naturally occurring radiation found in food, whereas no such change in risk assessment was found in the control group. A lower risk assessment for the education group as compared to the control group post-intervention also appeared for nuclear power plants, cosmic radiation, and background radiation. The results suggest that the measurement of attitude towards radiation was translated into how people assess the risk of radiation and their openness towards the use of radiation in particular contexts.

Medical radiation presented a unique case that did not follow the trends of overall radiation attitudes, nuclear power radiation attitudes, or societal approach to radiation attitudes. A similar result for medical radiation attitudes was found for participants who entered the study with a low attitude towards medical radiation, in that the educational intervention resulted in a significantly higher medical radiation attitude for those in the education treatment group as compared to the control group. However,
those who already had a perfectly favourable attitude towards medical radiation (in that their attitude was measured at a maximum score of 30 points) were found to have a significantly lower attitude towards radiation following the educational intervention. In a similar vein, CT scans were rated as riskier by education participants than control group participants following the intervention. While the particular aspect of the educational materials was responsible for attitude shifts is unknown, it is possible that observing the radiation doses connected to medical radiation in particular may have caused those with maximal pre-intervention medical radiation attitude scores to reconsider their position. Conversely, those with an initially low medical radiation attitude score may have had their concerns about radiation overall lowered to a degree that resulted in an increase in medical radiation attitude score, even in consideration of the doses present in medical procedures.

MacGregor (2002) found similar results in his measurement of risk assessment by university students who received an education packet on radiation. Those students rated nuclear power plants as less risky following the educational intervention, and medical x-rays and medical radiation treatments as riskier. The results in MacGregor’s work did not perfectly align with the results from this research, as the university participants in the former’s study also rated cosmic radiation and natural background radiation as riskier following the educational intervention, whereas natural background sources of radiation were judged to be less risky by participants following the educational intervention in this study. This suggests an overall lowering in risk perception of radiation for education group participants in this study, with the exception of when it is applied in medical procedures.

Pearson’s correlation was used to determine if a change in radiation attitude correlated with a change in knowledge about radiation, in order to assess whether it was the increase in knowledge which could be attributed to changes in attitude rather than
some other aspect of the educational intervention. Among the education group, there was a significant positive correlation with overall attitudes and nuclear power attitudes, and to a more limited extent for societal approach to radiation attitudes, indicating that the increase in knowledge may be responsible for the increase in attitudes (although, it is important to note the method of analysis does not allow for the establishment of causal relationships).

As with the other analyses performed, medical radiation was again an exception, and correlation between a change in knowledge and a change in medical radiation attitudes could not be established. This may be due to the differential influence of the educational treatment on medical radiation attitudes depending on if initial attitudes were high or low. Amongst all aspects of radiation studied, the linkage between radiation knowledge and attitudes is most tenuous for medical radiation.
CHAPTER FOUR: CONCLUDING THOUGHTS AND POLICY IMPLICATIONS

The results presented in this thesis provide evidence for some influence played by knowledge in the shaping of attitudes regarding science, at least as it pertains to radiation (and, even more specifically, radiation attitudes in Saskatchewan). As predicted by the information deficit model, lay attitudes towards radiation became more aligned with those shared by experts following knowledge acquisition about radiation. It has been previously established that experts view medical radiation as riskier and radiation from nuclear power plants or nuclear waste as less risky, while lay persons have the opposite assessment (Slovic 2012; Perko 2014). The educational intervention employed in this research moved attitudes held by participants towards those shared by experts in the field.

This research extends the existing body of work regarding the relationship between radiation knowledge and attitudes. The existing literature on attitude shifts and the information deficit model as it pertains to radiation attitudes is predominately in the form of regression modelling. This thesis incorporated a direct testing of the deficit model using an experimental construct rarely observed in the literature (e.g. MacGregor, 2002; Showers and Shrigley, 1995). The experimental methodology employed during this research importantly included a control group and did not limit the pool of participants to select groups such as university or school-aged students. Consequentially, the results provide a more robust testing of the information deficit model’s veracity.

Establishing a role for knowledge in attitude formation should not be construed as discounting or invalidating the myriad of other influences on attitude formation as proposed by other researchers (notably those proposed by Chandra [2014] in her thesis). Attitudes are a highly complex construct, and knowledge is likely one of several interacting factors that ultimately guide decision making and behavior. The work
presented in this thesis did not attempt to contextualize the influence of knowledge on attitude formation among other factors. Rather, the intention of the study was to establish that the role of knowledge on attitude formation could be measured using experimental methodologies, and that increasing radiation knowledge appears to have an influence on subsequent radiation attitudes. A more enhanced deficit model which considers the interplay of multiple factors and how the role of knowledge may be emphasized or attenuated by other aspects of attitude formation remains a fruitful area of future research. In this regard, a pure reading of the information deficit model, in that knowledge and knowledge alone influences attitude formation, is not suggested. Rather, the results presented here suggest that in an effort to move past the information deficit model, knowledge should not be lost as a consequential factor in attitude formation.

From a public policy perspective, the role of the citizen in decision making continues to evolve. As discussed in Chapter One, there is movement towards increased public participation in decision making processes, including those in relation to the study and application of science (Nisbet and Scheufele, 2009; Sturgis, 2014; Varner, 2014; Stilgoe et al., 2014; Burgess, 2014). Understanding attitudes and attitude formation among these citizens is helpful in predicting how the general public may participate in these processes, as attitudes have a direct correlation towards support and political preference (Frewer, 2004). The role of the citizen becomes particularly interesting when the topic at hand involves complex science, in which the general public cannot be expected to have expertise and yet still hold a vested interest in decision outcomes.

A robust understanding of the linkages between knowledge and attitudes is therefore helpful in predicting how any initial lack of knowledge may influence attitudes and citizen opinions, and how any attempt to address that knowledge gap may change (or not change) initial opinions. The results of this research indicate that simple provision of information about radiation, in certain contexts at least, can be expected to
change radiation attitudes. Policy makers can make use of this information when determining the most effective means to engage with the public on matters of science, including how any knowledge gap may be best addressed in a manner that will allow for a fulsome policy discussion in a deliberative setting.

The results presented here are most relevant, through their specificity, towards understanding the relationship between radiation knowledge and attitudes specifically in the province of Saskatchewan. This information could prove valuable should the province choose to pursue expansion of the uranium value chain, or explore implementation of nuclear power facilities in order to help achieve greenhouse gas emission targets. The Perrins report (Perrins, 2009) suggested that there is strong opposition to such initiatives in the province. However, these results indicate that efforts to educate the citizenry of Saskatchewan about nuclear power and radiation, if performed in the right manner, may shift attitudes and help to achieve social license for provincial radiation policies.

There are some caveats that should be considered when evaluating the results of this research. The measurement of radiation attitude changes in this research were limited to the response of participants to hypothetical questions. Participants were not being asked to actively undergo a medical procedure involving radiation or acquiesce to the construction of a nuclear power plant in their community. The implications, then, of the measurement in attitude shift should be interpreted with caution. Expressing a more favourable attitude towards radiation during a phone conversation regarding hypotheticals is not equivalent to ‘real-world’ scenarios with tangible implications.

Further, the individuals included in the study were not a perfect proxy for the entire population of Saskatchewan. Participants were more likely to be older, female, and have more advanced education than the general population. While the sampling procedure was an improvement to other studies, which used a far more limited
participant body, extension to the population of Saskatchewan as a whole should occur with caution. With that in mind, the general trend of a shift in radiation attitudes among participants was significant. Inclusion of those less represented in this study in the future would allow for confidence to be built in extending the results to the population of Saskatchewan as a whole.

There are several avenues of future research which would further illuminate the role of education in determining attitudes regarding radiation. From a persistence standpoint, returning participants to the study after a period of time has elapsed would demonstrate the degree to which the observes changes in knowledge and/or attitudes was permanent or transient. It would also be illuminating to increase the sample size of the participant pool to allow for demographic analysis of changes in radiation knowledge and attitudes, and whether different groups (e.g. age, gender, educational attainment, etc.) influence how education on radiation is interpreted and used to inform attitudes. Furthermore, the questions used to assess participants' knowledge and attitudes towards radiation did not include aspects of familiarity. For example, participants were not queried on whether they had recently or ever undergone a medical procedure involving radiation, lived near a nuclear power for a period of time, or lived through or were familiar with any number of nuclear power plant disasters (e.g. Fukushima, Three Mile Island, or Chernobyl). Incorporating such metrics in future studies would allow for determination of an associated role that familiarity and exposure to a nuclear technology may play in determining attitudes.

The methodology presented in this work provides a base situation in which information is provided to participants by an (assumedly) unbiased party in a manner that did not encourage high levels of engagement through debate or discussion. Modifications to the procedure would allow for further exploration of different aspects of risk communication, and which communication variables influence downstream attitude changes. While the receiving audience is an important factor in risk communication on
science, other aspects also play a role in determining the manner in which communications are interpreted, internalized, and accepted or rejected by a message recipient. Breakwell (2000) noted that not only characteristics of the audience are an important consideration, but so too are characteristics of the message (including, importantly, trust in the messenger) and the content of the message itself. Other researchers have also noted the importance of trust in how an audience receives and responds to new information (Covello, 2011; Frewer 2004). What is contained in the message also has an impact on message acceptance or rejection. Admission of risk uncertainty and indication of risks and not just benefits have been demonstrated to increase acceptance and confidence in research results (Frewer et al., 1998; Siegrist and Cvetkovich, 2001; Betsch and Sachse, 2013).

These variables could be manipulated in future research. For example, the educational materials could be modified to include a more intense focus on risks associated with radiation (e.g. consequences of historical nuclear plant disasters) to view the impact of negative information on attitude formation. The spokesman for the message could also be modified from an institutional researcher to a government or interest group to view the role that the messenger plays in recipient response to information and subsequent attitude formation. The resulting consequences for attitude shift would provide enlightening information on how the influence of knowledge on attitude formation may be situationally and contextually dependent.

Finally, a natural extension of this research involves information transmission during deliberative engagement. Further measurement of attitude shifts when participants interact with other people who have different perspectives and ideas would be illuminating in how attitude formation occurs in social settings. This approach would be valuable in a hypothetical scenario to measure the role of social interaction in of itself, as well as in a ‘real-world’ scenario where participants are invited to participate in a deliberative engagement process on a decision being actively undertaken by policy
makers (e.g. if Saskatchewan did decide to build a nuclear power facility). Including both situations would add the social component while providing information on how attitude responses may differ depending on if the scenario is hypothetical or a reality.
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APPENDIX A: INITIAL QUESTIONNAIRE

NUCLEAR SURVEY

March 2018

INTRO1./INTRO3
Hello, my name is (FIRST NAME ONLY) and I am a student at the University of Saskatchewan.
We are conducting a short 15-minute survey regarding radiation knowledge and attitudes in Saskatchewan.

INTRO2.
May I please speak with the person in your household who is 18 years of age or older and who is having the next birthday?

1. Yes, speaking CONTINUE
2. Yes, I'll get him/her REPEAT INTRODUCTION AND CONTINUE
3. Not available ARRANGE CALLBACK - REQUEST RESPONDENT FIRST NAME (RECORD IN NOTES) AND ARRANGE CALLBACK (PRESS THE CTRL AND END KEYS)

INTRO4.
I would like to invite you to participate in this short survey. Please be aware that participation is voluntary, and you may stop the survey at any time. If you decide to stop the survey during this call, all responses that you have provided will be deleted. All of the information that we collect today will be kept strictly confidential and will be stored securely at the University of Saskatchewan and University of Regina. Results from this survey will be reported in a summary format, so no individual responses will be identifiable. Your personal contact information will never be released. The University of Regina Research Ethics Board has approved this research project. If you have any questions, you can contact them at 306-585-4986 or research.office@uregina.ca. If you have any questions about the study, you can contact Dr.
Kathy McNutt, supervisor for this research project, at 306-585-4759. Would you like me to repeat any of this information?

Are you willing to participate?

1. Yes
2. No.  \textit{END SURVEY}
3. Later/Not right now  \textit{ARRANGE CALLBACK}

INTRO5.

Are you currently a resident of the province of Saskatchewan?

1. Yes
2. No  \textit{END SURVEY}
3. Choose not to answer  \textit{END SURVEY}

INTRO6.

\textit{(DO NOT READ)}

\textit{RECORD SEX FROM RESPONDENT VOICE.}

1. Male
2. Female

INTRO7.

Ok, I will start the survey now. For any question, if you wish, you may choose to not answer that question.

I would like to begin by asking you about your opinions and attitudes towards radiation.

For this first set of statements, please indicate if you strongly agree, somewhat agree, have a neutral opinion, somewhat disagree, or strongly disagree. Please let me know if you need me to repeat these options at any time.

For these questions, please keep in mind that there are no correct or incorrect answers.
(Q1-Q20 ARE RANDOMISED)

Q1. *
I would accept a nuclear power plant being built in Saskatchewan.

1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. (Don’t Know)
7. (Refused)

Q2. *
Nuclear power is a good option to generate electricity.

1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. (Don’t Know)
7. (Refused)

Q3. *
The benefits associated with nuclear power exceed the risks.

1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. (Don’t Know)
7. (Refused)
Q4.
Nuclear power plants are dangerous.

1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. (Don’t Know)
7. (Refused)

Q5.
I would be worried about living near a nuclear power plant.

1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. (Don’t Know)
7. (Refused)

Q6. *
I can trust employees to operate a nuclear power plant safely.

1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. (Don’t Know)
7. (Refused)

Q7.
Medical procedures that use radiation are dangerous.

1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. (Don’t Know)
7. (Refused)
Q8. *  
The benefits associated with medical radiation exceed the risks.

1. Strongly agree  
2. Somewhat agree  
3. Neither agree nor disagree  
4. Somewhat disagree  
5. Strongly disagree  
6. (Don’t Know)  
7. (Refused)  

Q9. *  
I would agree to undergo a medical procedure that involved radiation.

1. Strongly agree  
2. Somewhat agree  
3. Neither agree nor disagree  
4. Somewhat disagree  
5. Strongly disagree  
6. (Don’t Know)  
7. (Refused)  

Q10.  
I would be worried about the amount of radiation I could be exposed to during a medical procedure.

1. Strongly agree  
2. Somewhat agree  
3. Neither agree nor disagree  
4. Somewhat disagree  
5. Strongly disagree  
6. (Don’t Know)  
7. (Refused)  

Q11. *  
Medical procedures that use radiation are a good option for doctors to diagnose or treat a patient.

1. Strongly agree  
2. Somewhat agree  
3. Neither agree nor disagree  
4. Somewhat disagree  
5. Strongly disagree  
6. (Don’t Know)
Q12. *
I can trust doctors, nurses, and medical technicians to use radiation safely during medical procedures.

1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. (Don’t Know)
7. (Refused)

Q13. *
It is safe to use radiation to sterilize equipment such as medical tools.

1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. (Don’t Know)
7. (Refused)

Q14.
Eating food that has been exposed to radiation is dangerous.

1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. (Don’t Know)
7. (Refused)
Q15. *

It is ok for scientists to use radiation to conduct experiments.

1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. (Don’t Know)
7. (Refused)

Q16.

I am concerned about radiation exposure in my day to day life.

1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. (Don’t Know)
7. (Refused)

Q17.

As a society, we need to be more careful in how we use radiation.

1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. (Don’t Know)
7. (Refused)

Q18. *

As a society, we should continue to use radiation to benefit ourselves.

1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. (Don’t Know)
7. (Refused)
Q19. *
As a society, we should try to find new ways to use radiation that can make our lives better.

1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. (Don’t Know)
7. (Refused)

Q20.
Radiation is too dangerous for people to use safely.

1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. (Don’t Know)
7. (Refused)

Q21.
We will now move to some questions about the science behind radiation. For these questions, please just answer to the best of your knowledge.

First of all, how would you rate your confidence in your personal knowledge about radiation:

*(READ LIST)*

1. Completely confident
2. Very confident
3. Moderately confident
4. Slightly confident
5. Not at all confident
6. (Don’t Know)
7. (Refused)
For each of the following questions, please indicate whether you believe the answer to be true or false.

(Q22-Q37 ARE RANDOMISED)

Q22.
All radiation is man-made.

1. True
2. False
3. (Don’t Know)
4. (Refused)

Q23.
People are exposed to radioactive materials from the food we eat, the air we breathe, and in the soil around us.

1. True
2. False
3. (Don’t Know)
4. (Refused)

Q24.
If exposed, all forms of radiation can cause other objects to become radioactive.

1. True
2. False
3. (Don’t Know)
4. (Refused)

Q25.
Visible light, microwaves, and radio waves are examples of radiation.

1. True
2. False
3. (Don’t Know)
4. (Refused)
Q26.

If an accident occurred, a nuclear power plant could explode like a nuclear bomb.

   1. True
   2. False
   3. (Don’t Know)
   4. (Refused)

Q27.

Saskatchewan currently uses nuclear power to generate electricity.

   1. True
   2. False
   3. (Don’t Know)
   4. (Refused)

Q28.

Other provinces in Canada currently use nuclear power to provide electricity.

   1. True
   2. False
   3. (Don’t Know)
   4. (Refused)

Q29.

You are exposed to radiation everyday.

   1. True
   2. False
   3. (Don’t Know)
   4. (Refused)

Q30.

After being exposed to radiation in order to kill bacteria and pathogens, materials such as medical equipment or food remain radioactive.

   1. True
   2. False
   3. (Don’t Know)
   4. (Refused)
Q31.
All forms of radiation are equally dangerous to human health.
   1. True
   2. False
   3. (Don’t Know)
   4. (Refused)

Q32.
Most radiation that people receive on a day-to-day basis is from natural background sources.
   1. True
   2. False
   3. (Don’t Know)
   4. (Refused)

Q33.
Taking an airplane flight can increase your radiation exposure.
   1. True
   2. False
   3. (Don’t Know)
   4. (Refused)

Q34.
It is impossible to block radiation.
   1. True
   2. False
   3. (Don’t Know)
   4. (Refused)

Q35.
Different types of radiation vary in the amount of energy they contain.
   1. True
   2. False
   3. (Don’t Know)
   4. (Refused)
Q36.
Any amount of radiation exposure will cause illness.

1. True
2. False (Don’t Know)
3. (Refused)

Q37.
Nuclear waste from a nuclear power plant can remain hazardous for thousands of years.

1. True
2. False
3. (Don’t Know)
4. (Refused)

INTRO9.
For each of the following medical procedures, please indicate, with “yes” or “no”, if the procedure exposes a patient to radiation

(Q38-Q42 ARE RANDOMISED)

Q38.
Ultrasound

1. Yes
2. No
3. (Don’t Know)
4. (Refused)

Q39.
CT (computed tomography) scan

1. Yes
2. No
3. (Don’t Know)
4. (Refused)
Q40.

Mammogram
2. No
3. (Don’t Know)
4. (Refused)

Q41.

Dental x-ray
1. Yes
2. No
3. (Don’t Know)
4. (Refused)

Q42.

MRI (magnetic resonance imaging) scan
1. Yes
2. No
3. (Don’t Know)
4. (Refused)

INTRO10.

For the following pairs of radiation sources, please indicate which would expose you to more radiation

(Q43-Q45 ARE RANDOMISED)

Q43.

Radiation from living near a nuclear power plant for one year or radiation from a single dental x-ray.

1. Nuclear power plant
2. Dental x-ray
3. (Don’t Know)
4. (Refused)
Q44.
Radiation from living near a nuclear power plant for one year or total annual naturally occurring background radiation.

1. Nuclear power plant
2. Naturally occurring background radiation
3. (Don’t Know)
4. (Refused)

Q45.
Total annual naturally occurring background radiation or radiation from a single CT scan.

1. Naturally occurring background radiation
2. CT scan
3. (Don’t Know)
4. (Refused)

INTRO11.
I would now like you to assess the risks associated with some sources of radiation. For each of the following sources of radiation or activities, please indicate if you feel the source to be a no risk, low risk, a moderate risk, or a high risk to human health and safety.

(Q46-Q57 ARE RANDOMISED)

Q46.
Stored nuclear waste

1. No risk
2. Low risk
3. Moderate risk
4. High risk
5. (Don’t Know)
6. (Refused)
Q47.
Nuclear power plants
1. No risk
2. Low risk
3. Moderate risk
4. High risk
5. (Don’t Know)
6. (Refused)

Q48.
Radon gas
1. No risk
2. Low risk
3. Moderate risk
4. High risk
5. (Don’t Know)
6. (Refused)

Q49.
Nuclear medicine procedures
1. No risk
2. Low risk
3. Moderate risk
4. High risk
5. (Don’t Know)
6. (Refused)

Q50.
Cosmic radiation
1. No risk
2. Low risk
3. Moderate risk
4. High risk
5. (Don’t Know)
6. (Refused)
Q51.
Medical x-rays
1. No risk
2. Low risk
3. Moderate risk
4. High risk
5. (Don’t Know)
6. (Refused)

Q52.
Natural background radiation
1. No risk
2. Low risk
3. Moderate risk
4. High risk
5. (Don’t Know)
6. (Refused)

Q53.
Taking an airplane flight
1. No risk
2. Low risk
3. Moderate risk
4. High risk
5. (Don’t Know)
6. (Refused)

Q54.
Smoke detectors
1. No risk
2. Low risk
3. Moderate risk
4. High risk
5. (Don’t Know)
6. (Refused)
Q55.

Nuclear weapons testing

1. No risk
2. Low risk
3. Moderate risk
4. High risk
5. (Don’t Know)
6. (Refused)

Q56.

CT scans

1. No risk
2. Low risk
3. Moderate risk
4. High risk
5. (Don’t Know)
6. (Refused)

Q57.

Ingestion of radioactive materials that naturally occur in food

1. No risk
2. Low risk
3. Moderate risk
4. High risk
5. (Don’t Know)
6. (Refused)

INTRO12.

I would now like to ask you about your opinions on uses of radiation. For each of the following options, please indicate if you strongly agree, somewhat agree, neither agree nor disagree, somewhat disagree, or strongly disagree.

It is a good idea to use radiation for the following purposes:

(Q58-Q63 ARE RANDOMISED)
Q58.
Medical diagnosis and treatments
1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. (Don’t Know)
7. (Refused)

Q59.
Electricity generation
1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. (Don’t Know)
7. (Refused)

Q60.
Industrial applications (such as geological surveys)
1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. (Don’t Know)
7. (Refused)

Q61.
Scientific research

1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. (Don’t Know)
7. (Refused)

Q62.
Sterilizing medical equipment

1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. (Don’t Know)
7. (Refused)

Q63.
Decontaminating food

1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. (Don’t Know)
7. (Refused)

Q64.
I now just have a few demographic questions for you. These demographic questions are designed to help us identify trends in the data we are collecting. Again, I would like to emphasize that responses from all participants, including demographic questions, will be reported in a summary format.

In what year were you born?

1. (ENTER YEAR OF BIRTH)
2. (Refused)
Q65.
Do you live in an urban or rural location?
1. Urban
2. Rural
3. (Don’t Know)
4. (Refused)

Q66.
What was your household income level from all sources in 2017? Was it:
1. Less than $25,000
2. $25,000 to less than $50,000
3. $50,000 to less than $75,000
4. $75,000 to less than $100,000
5. $100,000 to less than $125,000
6. $125,000 to less than $150,000
7. $150,000 to less than $175,000
8. $175,000 or more
9. (Don’t Know)
10. (Refused)

Q67.
What is the highest level of education you have completed?
1. No schooling
2. Elementary
3. Secondary/High School
4. Technical/Community College
5. Bachelor’s Degree
6. Master’s Degree
7. Professional Designation
8. Doctorate
9. (Don’t Know)
10. (Refused)

Q68.
Do you have formal education in areas of science, technology, engineering, or mathematics?
1. Yes
2. No
3. (Don’t Know)
4. (Refused)
Q69.
Which of the following best describes your current employment situation?

1. Self-employed
2. Working for pay full-time
3. Working for pay part-time
4. Student and working for pay
5. Student and not working
6. Caring for children or family members
7. Retired
8. Unemployed or looking for work
9. Disabled
10. Other (Please specify)
11. (Refused)

Q70.
Do you have any children?

1. Yes
2. No
3. (Refused)

Q71.
In terms of Provincial political parties in Saskatchewan, which of the following political parties do you usually consider to most closely hold similar views to your own:

(READ LIST)

1. Conservative Party
2. Liberal Party
3. New Democratic Party
4. Green Party
5. Saskatchewan Party
6. Western Independence Part
7. Other (please specify)
8. (Don’t Know)
9. (Refused)
R1.

That is the end of our survey questions. Thank you very much again for participating.

This research project will continue beyond the survey we are doing today, and I am curious if you would be interested in continuing in the research project as a participant. The next phase of the project will include providing education materials about radiation to participants, or potentially asking them to be involved in focus groups about radiation use in Saskatchewan.

By continuing to participate in the research project, you will be entered to win a $100 pre-paid Visa gift card.

The research will be conducted over the next few weeks. Would you be interested in participating in this research?

1. Yes
2. No

END SURVEY

R2.

Okay, great. In order to involve you in this research project, and to enter you in the draw for the gift card, we will need to be able to contact you. Could you provide a telephone number or e-mail address for us to contact you?

(COLLECT PHONE/EMAIL)

We will also need a contact name so we can get in touch with you. I would like to remind you now that your name and contact information will not be associated with the responses you gave today, or with any responses you might give if you continue in the research project. Could I have your first name?

(COLLECT NAME)

1. (Enter name)
2. (Enter phone/email)
3. (Refused)

END SURVEY
END.

Thank you again for your time today. The results from this study are expected to be available by the end of 2018. If at any time you have any questions about the study, including the results, please contact Dr. Kathy McNutt at

* Indicates that the response was recoded to reverse the response score during analysis.
APPENDIX B: RADIATION EDUCATION BOOKLET

Education Materials

These materials contain information on the science of radiation and how people use radiation. It will allow you to understand where radiation comes from and how it can impact human health.

The materials have been broken into several sections:

1) Introduction to Radiation
2) Radiation’s Impact on the Human Body
3) Natural Sources of Ionizing Radiation
4) Man Made Sources of Ionizing Radiation
5) Exposure Comparison
6) Other Uses for Radioactive Materials

All of the information included in these materials has been gathered from official sources, professional publications, and scientific papers. A references and resources list can be found at the end of the materials.

Throughout the materials you will come across bolded words. These terms are important to understanding radiation. Definitions for these words can be found in a glossary at the back of the package.

A series of five videos are available on YouTube to accompany these reading materials. You made find it useful to watch the videos and read the related section in the education materials. The videos also have questions to help you check what you have learned.

Please read the education materials and watch the videos at your own pace. At any time, you can stop reading and return to the materials later.
Introduction to Radiation

Atoms – the building blocks of the universe

Before we begin a discussion about radiation, it is important to know what atoms are. Knowing what an atom is will help you to understand how radiation interacts with objects.

All matter in the universe is made up of extremely small structures called atoms. Everything around you, even your own body, is made up of atoms. Atoms are incredibly small. About 1 million atoms could fit across the width of a human hair.

Atoms have a very specific structure. They are composed of a central nucleus and electrons that orbit around the nucleus.

The nucleus contains protons and neutrons. Protons are positively charged and neutrons have no charge. Electrons, on the other hand, are negatively charged.

The number of protons in the nucleus specifies what type of chemical element the atom is. For example, carbon is an element with six protons in the nucleus. Other examples of different elements that you might have heard of before are oxygen, nitrogen, sodium, potassium, hydrogen, and helium.

Different elements bond together to form all of the matter in the universe.
What is radiation?

Radiation is something different than atoms. Radiation is energy moving through space. It can have two forms: waves of pure energy or moving particles that contain energy.

Radiation is around us all of the time. You are actually exposed to radiation every day. We may not always realize that some common things are actually types of radiation.

For example, one type of radiation is visible light. This radiation enters our eye, and allows us to see the world around us. Other examples of radiation are microwaves, which we use to quickly warm and cook our food, and radio waves that allow us to hear our favourite song.
Different types of radiation

Radiation can be classified into two important categories – **ionizing radiation** and **non-ionizing radiation**. These two categories of radiation differ in how much energy they contain. How much energy is contained in radiation impacts how that radiation interacts with objects.

![Electromagnetic Spectrum](image)

Shown in the picture above is a spectrum of different types of wave radiation. These types of wave radiation are separated based on how much energy each type has.

The types of radiation in blue are non-ionizing radiation. The types in red are ionizing radiation. Non-ionizing radiation contains less energy than ionizing radiation.

This means that in this picture, radio waves contain the least amount of energy, and gamma rays contain the most energy.
What happens when radiation meets an object?

When radiation moves around through space, it will eventually collide with an object. That object could even be a person like you!

When this happens, the energy that is contained in the radiation is transferred to the atoms in the object.

When non-ionizing radiation (for example radio waves, microwaves, or visible light) hits an atom, the energy is transferred from the radiation to the atom, but nothing else happens.

The story is different for ionizing radiation. When ionizing radiation (like ultraviolet, X-rays, or gamma rays) hits an atom, so much energy is transferred that electrons can be knocked away from their orbit around the nucleus. This changes the atoms, and can cause the connections or bonds between atoms to be broken.

Electrons being removed from atoms and bonds between atoms being broken are what can make radiation dangerous. This means that ionizing radiation is more hazardous and dangerous to our health than non-ionizing radiation.

Examples of ionizing radiation

We mentioned before that radiation could be waves or particles. There are examples of ionizing radiation for both types.

**Gamma rays** and **X-rays** are wave ionizing radiation.

**Alpha radiation, beta radiation** and **neutrons** are different types of particle ionizing radiation.
Breaking down the types of ionizing radiation

Not all ionizing radiation is the exact same. Alpha radiation, beta radiation, neutrons and waves differ in several important ways:

- They contain different amounts of energy;
- They are different sizes;
- Some are easier to block and stop moving;

**Alpha radiation (particle):** Alpha radiation is a type of particle ionizing radiation. It is composed of two protons and two neutrons.

Alpha radiation contains a large amount of energy, and is very large when compared to other types of radiation.

Due to its size, alpha radiation is easy to block. A sheet of paper or a dead layer of skin can quickly absorb alpha radiation. This stops it from moving any further.

**Beta radiation** (particle): Beta radiation is a small particle with the same mass as an electron. This means it is smaller than alpha radiation. Beta radiation also has less energy than alpha radiation.

Since it is smaller, beta radiation is harder to stop. Beta radiation can penetrate more deeply into our bodies than alpha radiation. Usually, beta radiation will stop before it reaches internal organs. A layer of
plastic, glass, or aluminum can block beta radiation.

**Gamma radiation (also called gamma rays) and X-rays:** Gamma radiation and X-rays are a type of wave radiation. They can be considered pure moving energy.

Gamma radiation and X-rays are very hard to block. Materials like thick layers of lead are needed to stop them.

Because gamma radiation and X-rays are so hard to stop, they can penetrate deep into our bodies and reach our organs. However, they have less energy than alpha or beta radiation.

**Neutron radiation:** Neutrons are particles that are found in the center of atoms. We saw them in the picture of an atom that we discussed earlier. Sometimes, neutrons can be released from the nucleus of atoms.

Neutrons are the type of radiation that is most difficult to stop. Thick layers of concrete or water are needed to stop neutron radiation.

**Does radiation make things radioactive?**

When something is radioactive it means that it is actively emitting ionizing radiation.

Being exposed to radiation does not necessarily make something radioactive. In fact, except for neutron radiation, this is very rare.

Except for in special circumstances, alpha, beta, gamma, and x-ray radiation all are unlikely to make another object become radioactive. This means, for example, that these types of radiation can safely be used to sterilize food or medical equipment. The food and medical equipment will not become radioactive.

Neutron radiation, on the other hand, is more likely to make other objects become radioactive. Because of the special way that neutron radiation interacts with atoms, it can cause those atoms to start emitting radiation themselves.

Non-ionzing radiation, like radio waves or visible light, does not make other objects become radioactive.
How is radiation measured?

Radiation can be measured in a few ways. For our discussion, we will focus on one of the most important questions about radiation – will it hurt us or make us sick?

Whether radiation will hurt us or not is dependent on several factors.

One is the type of radiation. Some types of radiation are more dangerous than others. This is because they contain different amounts of energy, or can penetrate more easily into our bodies.

Another factor is the tissue being exposed to radiation. Radiation is more dangerous to certain parts of the body. For example, the brain is more sensitive to radiation than our skin.

A radiation “dose”, or how much radiation we are exposed to, is measured in units called Sieverts (Sv). The Sievert unit standardizes the differences in radiation, so that we can make the effects of different sources of radiation more comparable. This means that 1 Sievert of alpha radiation has the same effect as 1 Sv of beta radiation or gamma radiation.

One Sievert represents a 5.5% chance of developing cancer as a result of radiation exposure.

Most of the radiation levels people encounter is very low. This is true whether that radiation is from natural sources or from man-made sources. To make the numbers more meaningful, effective doses are best represented by milliSieverts (mSv).

A milliSievert is 1/1000 of one Sievert. One milliSievert therefore would represent a 0.0055% chance of developing cancer.
Radiation’s Impact on the Human Body

What happens when radiation hits the body?

In order to be harmful, radiation must come into direct contact with the cells that make up our bodies. Cells are very small structures that make up all of the tissues of our bodies. Your skin, bones, heart, brain, and the rest of your body are made up of different types of cells.

Cells contain DNA. DNA contains the genetic information for an organism. It acts like an instruction manual for your cells, and tells them how to grow and behave.

Like everything else in the universe, cells and DNA are made up of different atoms. When ionizing radiation hits a person’s body, it can transfer energy to the atoms within our cells and DNA. This energy can remove electrons from atoms in our cells or DNA.

This process of energy transfer to our cells and DNA can cause damage, and stop the cells and DNA from working properly.

As we mentioned before, not all radiation is able to equally penetrate into our bodies. While alpha radiation contains a high amount of energy, it cannot penetrate past the outer layers of our skin. Alpha radiation is more dangerous when it is ingested or inhaled.

Other forms of radiation can penetrate our bodies more deeply. Beta radiation can reach cells deeper than alpha radiation. Gamma rays and X-rays can penetrate deep inside our bodies and reach internal organs.
What are the outcomes of radiation exposure?

Exposure to radiation can result in several different outcomes on the cells of our bodies:

1) The radiation does not cause any damage to the cell.

2) The radiation damages the cell, but the cell is able to locate the damage and repair it. The cell and the person are unharmed.

3) The cell is damaged beyond repair, and the cell dies.

   It is important to know that a small level of cell death occurs naturally in the body all of this time. This occurs even without radiation exposure and is not harmful to long-term health.

   Cell death is dangerous if a lot of cells die at the same time. This can occur if a person is exposed to a high amount of radiation over a short period of time.

4) The DNA of the cells can become damaged, but the cell does lives. This damage can lead to mutations. Mutations mean that the DNA in that cell is permanently changed. Mutations in DNA have the potential to cause cancer in the future.

These cell effects are not unique to radiation exposure. Cell damage, repair, death, and DNA mutation occur in our bodies every day. However, exposure to ionizing radiation makes it more likely that one of these events will occur. This in turn increases the chance of illness.
Radiation dose matters

The chance of a negative health impact from radiation depends on a few things.

The first is how much radiation you are exposed to. The more radiation you are exposed to (a higher dose) the more likely it is that the radiation will cause illness.

The second is how quickly the radiation exposure occurs. A radiation dose can happen all at once (an acute dose). Or, the exposure can occur over a long period of time (a chronic dose). Acute doses are more dangerous than chronic doses.

What dose of radiation is dangerous?

The Canadian Nuclear Safety Commission reports on levels of radiation that are known to cause illness. These numbers are summarized in the following table.

<table>
<thead>
<tr>
<th>Dose</th>
<th>Limit or Health Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>More than 5000 mSv</td>
<td>Dose which may lead to death when received all at once</td>
</tr>
<tr>
<td>1000 mSv</td>
<td>Dose which may cause symptoms of radiation sickness (e.g. tiredness and nausea) if received within 24 hours</td>
</tr>
<tr>
<td>100 mSv</td>
<td>Lowest acute dose known to cause cancer</td>
</tr>
</tbody>
</table>

100 mSv of radiation is the lowest known acute does to cause cancer. Lower dosages of radiation exposure might cause cancer. However, the rate of cancer from doses of radiation below 100 mSv is so low that it cannot be distinguished from natural rates of cancer.

High doses of acute radiation can cause a condition called radiation sickness. Acute exposures of 1000 to 4000 mSv can cause nausea, headache, loss of appetite, and changes in red blood cells. This can occur within hours or weeks after exposure. Loss of hearing, bleeding, and diarrhea can also occur.
Chronic doses of radiation have a different effect than acute doses. During chronic exposure, the body has time to repair some of the damaged cells. Acute doses have been estimated to be 1.5 to 2 times more effective at causing illness than chronic doses.
Natural Sources of Ionizing Radiation

Can radiation be naturally occurring?

Many people think that all ionizing radiation is man-made. However, this is not true. Most of the ionizing radiation we are exposed day-to-day to is naturally occurring.

We often term this naturally occurring ionizing radiation “background radiation”. There are several sources of background radiation.

Cosmic radiation

Cosmic radiation comes from sources outside the Earth. The sun is a main source of cosmic radiation. It can also come from far away sources beyond our solar system. The Earth’s atmosphere and magnetic field help to protect us from cosmic radiation. However, some still gets through.

Elevation can impact exposure to cosmic radiation. Higher elevations have less atmosphere to block radiation before it can reach our bodies. You would experience more radiation standing at the top of Mount Everest than you would standing beside the ocean in British Columbia.

For this same reason, you experience higher levels of radiation exposure during an airplane flight. During a flight, radiation exposure is approximately 100 times greater than levels at the ground. However, this exposure is still relatively small. You would need to fly 50 round-trip flights between Vancouver and Toronto to receive the same amount of radiation exposure that you are already receiving from other natural sources.
<table>
<thead>
<tr>
<th>Elevation (feet)</th>
<th>Cosmic Radiation Exposure (mSv per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (sea level)</td>
<td>0.26</td>
</tr>
<tr>
<td>500</td>
<td>0.27</td>
</tr>
<tr>
<td>1000</td>
<td>0.28</td>
</tr>
<tr>
<td>2000</td>
<td>0.31</td>
</tr>
<tr>
<td>4000</td>
<td>0.39</td>
</tr>
<tr>
<td>6000</td>
<td>0.52</td>
</tr>
<tr>
<td>8000</td>
<td>0.74</td>
</tr>
<tr>
<td>10000</td>
<td>1.07</td>
</tr>
</tbody>
</table>
**Terrestrial radiation**

We are also exposed to natural radiation that is created on Earth (called terrestrial radiation). Many naturally occurring elements in rocks and soil emit radiation. This includes uranium and certain kinds of carbon and potassium.

We can also breathe in radioactive material in the form of **radon gas**. Radon gas is emitted during the natural breakdown of uranium and radium in the ground. It is present in the air all around us, and can accumulate in basements, homes, and other buildings. Radon gas alone accounts for approximately 55% of the radiation exposure that an average person receives every year.

Not everyone receives the same amount of radon radiation exposure. Southern Saskatchewan and parts of northern Saskatchewan have high levels of radon gas. There can even be variation between homes in a location. Some homes in areas of low radon gas levels can still accumulate high amounts of radon.

**Ingestion and internal radiation**

Like everything else in the universe, our body is made up of atoms. Some of those atoms are radioactive. These radioactive atoms emit radiation from inside of our bodies.

We also are exposed to more radiation in the food that we eat. Radioactive atoms are part of all life on Earth.
How much background radiation are Canadians exposed to?

This table shows the amount of annual background radiation that a person would experience in different cities in Canada. The numbers are different for each city due to different amounts of cosmic, terrestrial, and inhalation based radiation (radon gas). A person in Regina would experience a higher level background radiation exposure as compared to many other Canadian cities, mostly because of radon gas.

<table>
<thead>
<tr>
<th>Canadian City</th>
<th>Total (mSv/y)</th>
<th>Cosmic Radiation (mSv/y)</th>
<th>Terrestrial Radiation (mSv/y)</th>
<th>Annual Inhalation Dose (mSv/y)</th>
<th>Internal Radiation (mSv/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CANADA</td>
<td>1.8</td>
<td>0.3</td>
<td>0.2</td>
<td>0.9</td>
<td>0.3</td>
</tr>
<tr>
<td>Whitehorse</td>
<td>1.9</td>
<td>0.5</td>
<td>0.2</td>
<td>0.9</td>
<td>0.3</td>
</tr>
<tr>
<td>Yellowknife</td>
<td>3.1</td>
<td>0.4</td>
<td>1.4</td>
<td>0.9</td>
<td>0.3</td>
</tr>
<tr>
<td>Victoria</td>
<td>1.8</td>
<td>0.5</td>
<td>0.1</td>
<td>0.9</td>
<td>0.3</td>
</tr>
<tr>
<td>Vancouver</td>
<td>1.3</td>
<td>0.5</td>
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<tr>
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The average person in Regina receives around 3.5 mSv of radiation from naturally occurring sources every year. Remember that the lowest known acute dose of radiation that will cause cancer is 100 mSv.

**3.5 mSv** is far below 100 mSv. However, the continued exposure to natural radiation can cause health effects over an extended period of time (chronic exposure). For example, it is estimated that 3000 Canadians die every year from lung cancer caused by radon gas.
Man-Made Sources of Ionizing Radiation

How do people use radiation?

Humans use radiation for many of our own purposes. This use can expose us to more radiation. Some human-made sources of ionizing radiation include:

- Smoke detectors;
- Medical procedures including X-rays, mammography and CT scans, and nuclear medicine procedures;
- Nuclear power plants;
- Coal power plants;
- Building materials and construction activities; and
- Fertilizers

For many of the human-caused radiation sources, the exposure for the average person is less than what we receive from natural background radiation. Higher levels of radiation can occur during certain medical procedures.
Which medical procedures use radiation?

Ionizing radiation is employed in several procedures in medicine. These procedures help medical professionals to diagnose illnesses and provide treatments to patients.

Some of the most common medical procedures that use ionizing radiation are scans that show internal structures, such as our bones, teeth, or internal organs. We have already discussed X-rays in this education booklet. X-rays are one example of using ionizing radiation to help doctors and dentists see inside of our bodies.

Other types of scans have a patient swallow or be injected with a substance that will emit radiation from inside our bodies. The radiation emitted is often gamma rays. This is what occurs in a CT (computer tomography) or PET (positron emission tomography) scan.

The amount of radiation we receive from these procedures can vary greatly, from an average of 0.1 mSv for x-rays to 14 mSv for PET scans.

Remember, this compares to an average of 3.5 mSv of ionizing radiation that we are exposed to every year from naturally occurring sources. This means that a single medical procedure can expose us to more radiation than we experience in an entire year from background sources.

Radiation medicine can also be used as a therapeutic treatment. Radiation can be used as a treatment for thyroid problems. It is also used as a treatment for cancer.

Doses of radiation experienced during these treatments can be very high. Exposure to radiation can be as high as 70,000 mSv to 80,000 mSv during a radiation therapy treatment session.

Other medical procedures might seem like they use radiation, but they do not.

Ultrasounds and MRI (magnetic resonance imaging) scans are two such procedures. Ultrasounds use sound waves and MRIs use a strong magnetic field to create a scan of our bodies. Neither of these procedures exposes a patient to radiation.
**Nuclear power plants**

Electricity is generated at many power plants by heating water and making steam. The steam turns a turbine, and electricity is generated. This method is used at many different types of power plants. Coal, natural gas, and **nuclear power plants** all use steam to create electricity.

The difference between these types of power plants is how they make heat to produce steam. Coal and natural gas plants generate heat by burning coal or natural gas.

Nuclear power plants use a **nuclear chain reaction** to make heat. A nuclear chain reaction is a self-sustaining series of **nuclear fissions**. A nuclear fission is what we call the process of an atom's nucleus splitting into smaller parts.

In a nuclear power plant, this process begins with a neutron hitting an atom of uranium. This causes the uranium atom to split in two, and to release more neutrons. These neutrons move on to hit more atoms of uranium, which also split apart, and release more neutrons. This process is repeated over and over, and is called the nuclear chain reaction.

You can see an example of the nuclear chain reaction in the fourth educational video.

There are two important things that are released during the nuclear chain reaction. The first is heat. It is this heat that is captured and used to generate steam and electricity.

The other thing that is released is radiation. Alpha, beta, gamma, and neutron radiation, are all created inside of a nuclear power plant.

**Does Saskatchewan have nuclear power plants?**

Saskatchewan does not currently have any nuclear power plants. However, 16% of all electricity in Canada comes from nuclear power. These plants are mostly located in Ontario, which have been operating since the 1960's.
How is the radiation from a nuclear power plant blocked?

This radiation that is created inside of a nuclear power plant needs to be blocked and contained so that it cannot escape out into the surrounding environment.

Earlier, we discussed how different materials are needed to block different types of radiation. Alpha and beta radiation are relatively easy to stop, but gamma and neutron radiation are more difficult, and can penetrate more deeply into materials.

Since all of these different types of radiation are released inside of a nuclear reactor, a nuclear power plant needs to be surrounded by think layers of concrete or water. This stops the radiation from the nuclear chain reaction and keeps it from escaping out into the environment.

What other safety mechanisms do nuclear power plants have?

Proper safety mechanisms at nuclear power plants are critical to make sure the public is safe. Nuclear power plants have a number of safety mechanisms:

1) Sometimes, it might be necessary to quickly shut down a nuclear power plant. Shut off rods can be inserted into a nuclear reactor and can very quickly stop the nuclear chain reaction.

2) Once shut down, nuclear power plants need to be manually restarted, and cannot spontaneously start going again on their own.

3) Emergency cooling water systems make sure that the nuclear power plants do not get too hot.

4) Backup power systems make sure that everything keeps working properly, even if electricity to the nuclear power plant is disrupted.

5) Nuclear power in Canada is constantly monitored by the Canadian Nuclear Safety Commission. The Commission makes sure that nuclear power plants are properly maintained. They also make sure radiation escaping into the environment stays below the safety limits.
Nuclear power safety – radiation exposure and explosions

Despite the concerns surrounding radiation from nuclear power plants, the average exposure to radiation from a nuclear power plant is actually very low.

On average, living by a nuclear power plant for one year would expose a person to 0.04 mSv of ionizing radiation. This compares to 3.5 mSv from natural background radiation.

Another common concern is that nuclear power plants can explode like a nuclear bomb. This is not true. Nuclear bombs and nuclear power plants use radioactive material differently. A nuclear power plant could never explode like a nuclear bomb.
How does Canada deal with nuclear waste?

The Canadian Nuclear Safety Commission also regulates nuclear waste in Canada.

The most important nuclear waste from power plants is “high-level” waste. This waste is used up nuclear fuel. High-level waste can remain radioactive and toxic for thousands of years. Therefore, careful and long-term waste management techniques are needed.

The Canadian Nuclear Waste Management Organization (NWMO) handles the storage of high-level waste. This waste undergoes two storage steps – wet storage, and dry storage.

1) Wet storage involves storing waste in pools of water. This water provides cooling for the spent fuel, which is still giving off heat. It also blocks radiation. Two-meter thick reinforced concrete walls provide additional shielding. High-level waste remains in wet storage for seven to ten years.

2) Following wet storage, the waste is transferred to dry storage containers. These containers are either concrete silos or reinforced concrete canisters with carbon steel shells. These silos and canisters block the radiation that is still being emitted from the waste.

Radioactive waste does not take up a lot of space. Since the onset of nuclear power in Canada, all of the high-level waste could fit into the space of seven hockey rinks, from the ground to the top of the boards.
Exposure Comparison

The graph below compares different sources of natural and man-made ionizing radiation. It lists in mSv how much radiation occurs from each source.

For medical procedures and increased exposure from flying, the number represents the exposure from a single procedure or flight. The other numbers are how much exposure occurs over one year.

On the very left is the annual amount of ionizing radiation that a person experiences from naturally occurring background sources. It may surprise you that naturally occurring radiation is one of the largest sources of ionizing radiation that we experience.
In Regina, naturally occurring radiation is responsible for 3.5 mSv of exposure every year.

In comparison, living beside a nuclear power plant would expose a person to an additional 0.004 mSv of ionizing radiation per year.

As you can see on the right, a single medical procedures can exposure a person to more ionizing radiation than any of these other sources.
Other Uses for Radioactive Materials

In addition to medical procedures and electricity generation, radiation is used for other purposes in Canada.

The Canadian Light Source synchrotron, located in Saskatoon, Saskatchewan, makes the use of radiation to conduct many scientific experiments. This includes experiments in health, the environment, agriculture, and creating new materials. These experiments help scientists and engineers to better understand the world around us, to develop new medical procedures, and to create new products.

Radiation is also used to sterilize medical equipment, blood donations, cosmetics and food. By exposing these things to radiation, dangerous pathogens and bacteria are killed. After being exposed to radiation, the items themselves do not become radioactive. This means that the items cannot expose a person to ionizing radiation.

Finally, radiation is used in many industrial practices. For example, industrial radiography can be used to ensure the integrity of pipelines or structures and to analyze ground density.
Glossary

**Acute dose** – exposure to a level of radiation instantaneously or over a short period of time.

**Alpha radiation** – a form of particle radiation comprised of two neutrons and two protons. Alpha radiation is an example of ionizing radiation.

**Atoms** – A unit of matter and the smallest form of a chemical element. Atoms are made of a central nucleus with protons and neutrons, and electrons that orbit around the nucleus.

**Background radiation** – the naturally occurring ionizing radiation present in the environment. Sources include cosmic radiation from space, radiation from the soil around us, inhaled radiation from radon gas, ingested radiation in food, and naturally occurring radiation in the atoms of our bodies.

**Beta radiation** – a form of particle radiation comprised of an electron or positron. Beta radiation is an example of ionizing radiation.

**Cell** – the smallest structural and functional unit of an organism. All living tissues are comprised of cells.

**Chronic dose** – exposure to a level of radiation over a long period of time.

**Cosmic waves (rays)** - radiation that originates from beyond the Earth’s atmosphere.

**DNA (deoxyribonucleic acid)** - a molecule that contains the genetic information for the growth and development of an organism.

**Electron** – a subatomic particle with a negative charge that orbits around the nucleus of an atom.

**Element** – elements are defined by atoms that have the same number of protons in the nucleus. There are 118 identified elements which come together to make up all matter in the universe. Some examples are oxygen, nitrogen and carbon.

**Gamma radiation (Gamma rays)** – a high-energy form of electromagnetic (or wave) radiation. Gamma rays are an example of ionizing radiation.
**High-level waste** – Highly radioactive material left as a byproduct from nuclear fission in nuclear reactions. It can take the form of used fuel or waste left after used fuel is reprocessed.

**Ionizing radiation** – Radiation that has enough energy to remove electrons from orbit around a nucleus.

**Mutation** – A permanent alteration in DNA.

**Neutron** – An uncharged subatomic particle found in the nucleus of an atom.

**Neutron radiation** – A type of ionizing radiation composed of free neutrons released after nuclear fission. Neutron radiation is an example of ionizing radiation.

**Non-ionizing radiation** – Radiation that does not have enough energy to remove electrons from orbit around a nucleus.

**Nuclear chain reaction** – A self-sustaining series of nuclear fissions within a nuclear reactor.

**Nuclear fission** – When one atom splits into two smaller nuclei. This can cause the release of free neutrons and ionizing radiation along with a large amount of energy.

**Nuclear power plant** – An electricity generation plant that uses the energy released from nuclear fissions to heat water into steam. The steam is used to turn a turbine and create electricity.

**Nuclear reactor** – The portion of a nuclear power plant that houses, starts, and controls a nuclear chain reaction.

**Nuclear (radioactive) waste** – Waste from a nuclear power plant that contains radioactive material.

**Nucleus** – The center of an atom made up of protons and neutrons.

**Proton** – A positively charged subatomic particle found in the nucleus of an atom.

**Radiation** – The release or transfer of energy in the form of waves or particles moving through space or matter.
**Radioactive** - A material that is releasing ionizing radiation.

**Radon gas** – A naturally occurring radioactive gas that is generated from the radioactive decay of elements in soil and rocks.

**Sievert** – a unit of measure for the health impacts from a radiation exposure event. It represents the probability of developing cancer in the future as a result of a radiation exposure event.

**X-rays** – A high-energy form of electromagnetic (wave) radiation. They are commonly used in medical procedures. X-rays are an example of ionizing radiation.
References and Resources

Effective Doses in Radiology and Diagnostic Nuclear Medicine: A Catalog

High Level Nuclear Waste – Canada Nuclear Safety Commission
http://nuclearsafety.gc.ca/eng/waste/high-level-waste/index.cfm

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Ionizing Radiation: A Tutorial on Sources and Exposures - Donald MacGregor.
https://www.osti.gov/em52/final_reports/69904.pdf

Nuclear Power in Canada – World Nuclear Association

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Radiation Basics – United States Nuclear Regulatory Commission
https://www.nrc.gov/about-nrc/radiation/health-effects/radiation-basics.html

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Radiation Protection Regulations – Justice Laws

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http://www.radiationsafety.ca/resources/onlinecourse#
Radioisotopes – Canada Nuclear Safety Commission
http://nuclearsafety.gc.ca/eng/resources/radiation/introduction-to-radiation/radioisotopes.cfm
Video #1
An Introduction to Radiation

Welcome to the first educational video about the science and application of radiation.

This first video will be an introduction to the concept of radiation. We will talk about what radiation is and how radiation behaves.
Before we get going talking about radiation itself, we first need to understand the idea of the atom. Knowing what an atom is, and what it looks like, is important for understanding how radiation interacts with objects.

Seen here is a picture of an atom. All matter in the universe is made up of atoms – The sun in the sky, the ground underneath our feet, an apple you eat for breakfast, your television, and even your body. All of these things are made up of atoms.

Atoms have a very specific structure. The center of the atom is called the nucleus. You can see the nucleus at the center of the atom here in this picture. The nucleus is made up of two small particles – protons in red, and neutrons in grey. Electrons, seen here in blue, orbit around the nucleus.

There are over 100 different types of atom, and you have probably heard of some – oxygen, nitrogen, carbon, sodium, potassium, hydrogen, helium – these are all different types of atoms, called elements. Atoms of these elements come together and form bonds to make up everything around us.
Radiation is something different than atoms. Radiation is best thought of as the movement of energy through space.

This movement of energy can happen in a few different ways. Shown here are two different types of radiation – particle radiation, and wave radiation. Both of these types of radiation represent the movement of energy through space.
You might be surprised to learn that you actually encounter radiation every day. The heat that we feel from the sun is one example of radiation. The light that comes from the sun or a light bulb and allows us to see is another form of radiation. So are microwaves that we use to warm and cook our food, or radio waves that allow us to listen to our favourite songs. All of these are different types of radiation that are moving through space all around us.
Not all radiation is the same. We have already discussed how some radiation comes in particles, and others in waves. Another difference is that different types of radiation carry different amounts of energy.

Shown here is a spectrum of different types of wave radiation, based on how much energy each type has. The categories on the left, starting with radio waves, have the least amount of energy, while gamma rays on the right have the most amount of energy.

How much energy is contained in radiation is important for understanding what happens when radiation interacts with an object like you or me.

The radiation here is classified into two types, based on how much energy is contained in that radiation. In blue (with low amounts of energy) we have non-ionizing radiation, and in red (with high amounts of energy) we have ionizing radiation.
How much energy is contained in radiation tells us what happens when that radiation hits an atom.

When radiation is moving through space, it will eventually collide with an object. The energy that is contained in the radiation will then be transferred from the radiation, to the atoms in that object.

When ionizing radiation hits an atom, so much energy is transferred that electrons can be knocked away from their orbit around the nucleus. This can change the atom, and can also cause the connections or bonds between atoms to be broken.

On the other hand, non-ionizing radiation does not contain enough energy to remove electrons from their orbit around the nucleus.

It is the process of electrons being removed from atoms and bonds between atoms being broken that makes ionizing radiation particularly dangerous. This means that ionizing radiation is much more hazardous and dangerous to our health than non-ionizing radiation.
Types of Ionizing Radiation

<table>
<thead>
<tr>
<th>Waves</th>
<th>Particles</th>
</tr>
</thead>
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<tr>
<td>Ultraviolet</td>
<td>Alpha particles</td>
</tr>
<tr>
<td>X-rays</td>
<td>Beta particles</td>
</tr>
<tr>
<td>Gamma rays</td>
<td>Neutrons</td>
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</tbody>
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Here are some examples of wave and particle radiation that are ionizing.

Under the wave types are ultraviolet, x-rays, and gamma rays. You may have heard of some of these before. X-rays, for example, are used by doctors and dentists to take pictures of our bones and teeth. Alpha particles, beta particles, and neutrons are types of ionizing particle radiation.
Sometimes, we want to block radiation and stop it from moving. For example, when you get a dental x-ray you might be covered by a lead blanket. That blanket stops the x-rays from hitting other parts of your body.

Just like different types of radiation have different amounts of energy, they also have different sizes. These differences mean that different types of radiation are easier or harder to block.

Some types of radiation are very easy to stop. For example, alpha radiation can be stopped by as little as a single sheet of paper, and beta radiation can be stopped with a sheet of aluminum.

Other types of radiation are more difficult to block. A thick layer of lead is needed to stop x-rays and gamma rays, and thick layers of concrete or water are needed to stop neutron radiation.

Knowing how we can block radiation is important for keeping people safe around radiation sources. We will discuss more about these sources in later videos.
The final idea for us to discuss on the science behind radiation is whether radiation can make things radioactive.

When something is radioactive that means that it is actively emitting radiation. But just because something is exposed to radiation, that does not necessarily mean that that object itself will become radioactive and start emitting radiation.

Except for in special circumstances, alpha, beta, gamma, and x-ray radiation are all unlikely to make another object become radioactive. This means, for example, that these types of radiation can safely be used to sterilize food or medical equipment without causing those objects to become radioactive themselves.

Neutron radiation, on the other hand, is more likely to make other objects become radioactive. This is because of the special way that neutron radiation interacts with atoms. It can cause those atoms to start emitting radiation themselves.

Non-ionizing radiation, like radio waves, does not make other objects become radioactive.
Questions

1. True or false: you encounter radiation every day?

2. True or false: non-ionizing radiation is more dangerous than ionizing radiation?

3. True or false: Exposure to any radiation will make an object radioactive.

To check your knowledge about the science of radiation, try to answer these five questions. You can pause the video to think about the questions for as long as you like. When you are ready to see the answers, press play.
Questions

4. Different type of radiation vary in the amount of energy they contain?

5. It is impossible to block radiation?

To check your knowledge about the science of radiation, try to answer these five questions. You can pause the video to think about the questions for as long as you like. When you are ready to see the answers, press play.
Answers

- True or false: you encounter radiation every day? True. Radiation is around us all of the time, every day. Most of this radiation is not dangerous to human health. We will talk more about radiation sources in videos 3 and 4.

- True or false: non-ionizing radiation is more dangerous than ionizing radiation? False. Non-ionizing radiation, like visible light or radio waves, is less dangerous than ionizing radiation, like alpha, beta, gamma, and neutron radiation and x-rays.

- True or false: Exposure to any radiation will make an object radioactive. Neutron radiation is the most likely type of ionizing radiation that will make another object radioactive. Other types of radiation (such as alpha, beta, or gamma radiation) usually do not make objects become radioactive.

To check your knowledge about the science of radiation, try to answer these five questions. You can pause the video to think about the questions for as long as you like. When you are ready to see the answers, press play.
Answers

4. Different type of radiation vary in the amount of energy they contain? True. Different types of radiation have different amount of energy. For example, gamma rays (a type of ionizing radiation) has more energy than visible light (a type of non-ionizing radiation).

5. It is impossible to block radiation? False. It is possible to block radiation, though some radiation (like neutron radiation) is more difficult to block than other types (like alpha radiation). You can block alpha radiation with a sheet of paper, but need thick concrete or water to stop neutron radiation.

To check your knowledge about the science of radiation, try to answer these five questions. You can pause the video to think about the questions for as long as you like. When you are ready to see the answers, press play.
Video #2
Radiation’s Impact on the Human Body

This video will discuss what impact ionizing radiation can have on the human body.
Measuring Radiation

Unit of measure = Sievert (Sv) or milliSievert (mSv)

1 Sv = 1000 mSv

Sieverts measure health risk from radiation

1 Sv = 5.5% chance of developing cancer
1 mSv = 0.0055% chance of developing cancer

Before we begin our discussion about how radiation impacts the human body, we need to briefly discuss how we measure radiation.

Radiation doses are measured in a unit called the Sievert. We discussed in the first video that not all types of ionizing radiation are the same. Different types of ionizing radiation can differ in the amount of energy they carry, their size, and how easily they are able to penetrate into different materials.

The Sievert unit standardizes these differences in radiation, so that we can make the effects of different sources of radiation more comparable. The Sievert measures the health risk that ionizing radiation can have on the human body. The standardization means that 1 Sievert of alpha radiation is equivalent to 1 Sievert of beta or gamma radiation, for example.

Often, because the numbers are very small when we discuss radiation doses, we use the unit milliSievert instead of Sievert. One Sievert is equivalent to 1000 milliSieverts.

In health terms, a Sievert represents a 5.5 percent chance of the development of cancer as a result of exposure to ionizing radiation. This means that one milliSievert represents a 0.0055 percent chance of cancer development.

More information about measuring radiation is available in your education booklet.
Our bodies are made up of very small structures called cells. Different cells make up all of the different parts of our bodies. Bone cells make up our bones, muscles cells our muscles, and so on.
What a cell looks like, and how it functions, is determined by the DNA contained within each cell. DNA acts like an instruction manual that tells each of our cells what to do.
Ionizing radiation can be harmful when it comes into contact with our cells. Remember that when ionizing radiation hits an atom, the energy from the radiation is transferred to that atom. This can break bonds between atoms, and remove electrons from their orbit around the nucleus.

Also remember that it is only ionizing radiation that has this effect. Non-ionizing radiation such as radio waves does not have enough energy to have this effect on atoms.
Our cells are all made up of atoms. When ionizing radiation hits the atoms in our cells, the energy is transferred from the radiation to those cellular atoms. This can damage the cell itself, or the cell’s DNA.

Alpha radiation is not as dangerous as other types of ionizing radiation, because it is not able to penetrate past our skin. This means that an alpha radiation source would need to be ingested or inhaled to be harmful. Other types of radiation however, such as beta and gamma radiation seen here are able to penetrate past our skin, and hit cells deep inside of our bodies.
1. The radiation could cause damage, but the cell is able to locate and repair the damage, and no harmful effects occur.

2. The radiation could cause the cell to die.

3. The DNA of the cell could become damaged, but the cell does not die. This damage can lead to mutations in the DNA. This has the potential to cause cancer in the future.

Being exposed to any amount of radiation does not necessarily mean that something bad will happen. There are several possible outcomes:

   The radiation could cause damage, but the cell may be able to locate and repair the damage, and no harmful effects occur.
   The radiation could cause the cell to die.
   The DNA of the cell could become damaged, but the cell does not die. This damage can lead to mutations in the DNA and has the potential to cause cancer in the future.
More radiation (higher dose) is more likely to cause a negative health effect.

A dose that occurs all at once (acute dose) is more likely to cause illness than exposure over a long period of time (chronic dose).

Radiation’s impact on the body is dependent on how much radiation you are exposed to, and on how rapidly that exposure occurs. The more radiation you are exposed to (or the higher the dose), the more likely it is that a harmful outcome will occur.

A radiation dose that occurs all at once (called an acute dose) is more harmful than an equivalent dose that occurs over a long period of time (called a chronic dose).
This table shows the effects that certain radiation doses will have on a person's health.

An acute dose of 5000 mSv may lead to death.

A dose of 1000 mSv received over the course of 24 hours can lead to symptoms of radiation sickness such as tiredness and nausea.

An acute dose of 100 mSv is the lowest dose known to result in the development of cancer.

These reference numbers will be important in the next videos as we discuss natural and man-made radiation sources.
Questions

1. True or false: All forms of radiation are equally dangerous to human health?

2. True or false: Any amount of radiation exposure will cause illness?

Here are two questions about the health impacts of radiation. Pause the video to think about your answers. When you are ready to continue, hit play.
Questions

1. True or false: All forms of radiation are equally dangerous to human health? False. Ionizing radiation (such as alpha, beta, or gamma radiation) can be dangerous to human health, but non-ionizing radiation (like radio waves) is not dangerous. Also, different forms of ionizing radiation are not all equally dangerous. For example, alpha radiation needs to be ingested or inhaled to be hazardous to human health.

Here are two questions about the health impacts of radiation. Pause the video to think about your answers. When you are ready to continue, hit play.
Questions

2. True or false: Any amount of radiation exposure will cause illness? **False.** Being exposed to radiation will not necessarily cause illness. Illness is more likely to occur if the radiation dose is higher, and if it occurs all at once (an acute dose). A 100 mSv dose of ionizing radiation is the lowest known amount to cause the development of cancer.

Here are two questions about the health impacts of radiation. Pause the video to think about your answers. When you are ready to continue, hit play.
Despite the common misconception, not all ionizing radiation is man made. In fact, most of the ionizing radiation we experience on a day-to-day basis is naturally occurring.

In this video, we will discuss the natural sources of ionizing radiation that we all experience every day.
There are several sources of naturally occurring ionizing radiation. We often call natural sources of radiation background radiation because they occur in the background of our lives, every day.

We will discuss three main sources of background or naturally occurring radiation.

The first is called cosmic radiation. Cosmic radiation comes from sources outside of the Earth. One of these sources is our own Sun, which can shoot ionizing radiation out into space. There are also other sources of ionizing radiation throughout the galaxy and the rest of the universe.

This ionizing radiation moves through space until it comes into contact with the Earth. Eventually, the radiation will make its way down to us on the Earth’s surface and come into contact with our bodies. The Earth’s atmospheric and magnetic field can shield us from some of this radiation by blocking it from reaching the Earth’s surface.

This means that the higher your elevation, the more cosmic radiation you would experience. This is because the Earth’s atmosphere is thinner at higher elevations, like at the top of Mount Everest, than it is at lower elevations.

For this reason, you are exposed to increased levels of cosmic radiation during a flight on an airplane. However, this increase is relatively small. You would need to take 50
Round trip flights between Toronto and Vancouver to experience an increased amount of radiation equal to what you already are exposed to from natural background radiation.

The next type of naturally occurring radiation is terrestrial radiation. Terrestrial radiation is released from certain elements in the soil and rocks that make up the Earth.

An example of this type of radiation is radon gas. Radon gas is created from the natural breakdown of uranium and radium in the ground. Radon gas is present in the air all around us, releasing ionizing radiation, and can be inhaled. It is particularly dangerous when it accumulates in our homes and basements. Radon gas alone accounts for around 55 percent of the radiation exposure that the average person receives every year.

The final source of background ionizing radiation is from ingestion. There are radioactive particles located within the food we eat every day. We ingest these particles, and they can even become part of our bodies, continuing to release radiation.
This chart shows the amount of radiation that Canadians experience every year from naturally occurring background radiation sources. Regina is highlighted in red.

The average person in Regina receives around 3.5 mSv of radiation from naturally occurring sources every year. Remember that the lowest known acute dose of radiation that will cause cancer is 100 mSv.

3.5 mSv is far below this threshold. However, the continued exposure to natural radiation can cause health effects over an extended period of time. For example, it is estimated that 3000 Canadians die every year from lung cancer caused by radon gas.

In the next few videos, we will compare this amount of naturally occurring radiation to man-made ionizing radiation sources, such as radiation we use in medical procedures or radiation from nuclear power plants.
Video #4
Man-Made Sources of Ionizing Radiation

In this video, we will discuss exposure to ionizing radiation that occurs due to man-made sources.
Man Made Sources of Radiation

- Medical Procedures (X-rays, Mammography, CT scans)
- Nuclear Power Plants
- Coal Power Plants
- Construction activities
- Fertilizers
- Smoke Detectors

There are many sources of radiation that occur from human activities. You might be familiar with radiation that we use in medical procedures, such as x-rays, and have probably heard that radiation occurs in association with nuclear power plants.

You might be surprised to learn that radiation is also released during other activities. Coal power plants, construction activities, and using fertilizers can also expose people to ionizing radiation. There is even a very small amount of radiation that is emitted from your home smoke detector.

It’s important to remember that just because an activity includes ionizing radiation, that does not necessarily make it inherently more dangerous than naturally occurring ionizing radiation. It is always important to consider how much radiation the activity exposes you to, and what we can do to protect ourselves.
Man Made Sources of Radiation

- Medical Procedures (X-rays, Mammography, CT scans)
- Nuclear Power Plants
  - Coal Power Plants
  - Construction activities
  - Fertilizers
  - Smoke Detectors

In our discussion in this video, we will focus on two sources of man-made ionizing radiation – radiation from medical procedures, and radiation from nuclear power plants.
Radiation in Medicine

- X-rays (0.1 mSv)
- Mammography (0.4 to 3 mSv)
- CT Scans (10 mSv)
- PET Scans (14 mSv)
- Radiation Treatments (70,000 to 80,000 mSv)
- Naturally occurring radiation = 3.5 mSv per year

Many medical procedures use ionizing radiation. This radiation allows doctors to look inside our bodies to identify problems or helps doctors in treating illnesses.

Some of the most common medical procedures that use ionizing radiation are scans that show internal structures, such as our bones, teeth, or internal organs. X-rays, mammographies, CT scans, and PET scans are all procedures that allow medical professionals to see into our bodies and look for problems. This can occur by scanning our bodies from the outside, like in an x-ray, or by having a patient swallow or be injected with a substance that will emit radiation from inside our bodies. This is what occurs in a CT or PET scan.

The amount of radiation we receive from these procedures can vary greatly, from an average of 0.1 mSv for x-rays to 14 mSv for PET scans.

Remember, this compares to an average of 3.5 mSv of ionizing radiation that we are exposed to every year from naturally occurring sources.

Other medical treatments, such as radiation therapy, use extremely high amounts of radiation to try and treat diseases such as cancer. Radiation treatments can expose patients to as much as 70 or 80,000 mSv of radiation. These are high amounts of radiation used very carefully and only when your doctor determines that it is necessary.
Other medical procedures might sometimes seem like they use ionizing radiation, when they actually do not.

Two common procedures that people think might use ionizing radiation are ultrasounds and MRIs. Neither of these procedures involves the use of ionizing radiation. Ultrasounds use sound waves to allow for doctors to see inside our bodies, and MRI's use magnetism.
Other medical procedures might sometimes seem like they use ionizing radiation, when they actually do not.

Two common procedures that people think might use ionizing radiation are ultrasounds and MRIs. Neither of these procedures involves the use of ionizing radiation. Ultrasounds use sound waves to allow for doctors to see inside our bodies, and MRI's use magnetism.
Nuclear power plants are used in many places to generate electricity. Nuclear power is an interesting source of electricity, because its regular use does not emit greenhouse gases such as carbon dioxide that can contribute to global warming.

As of today, Saskatchewan does not have any nuclear power plants. But other places in Canada do. 16% of Canada’s electricity comes from nuclear power. Ontario, for example, has been using nuclear power for electricity since the 1970s.

There are many misconceptions about nuclear power plants, including that they always release a large amount of radiation into the surrounding environment, or that they could explode like a nuclear bomb in the case of an accident. Neither of these misconceptions is true.
Nuclear power plants use something called a nuclear chain reaction to generate electricity.

A nuclear chain reaction is a self-sustaining series of nuclear fissions. A nuclear fission is what we call the process of an atom's nucleus being split into smaller parts.

In a nuclear power plant, this process begins with a neutron hitting an atom of uranium. This process causes the uranium atom to split in two, and to release more neutrons. These neutrons move on to hit more atoms of uranium, which also split apart, and release even more neutrons. This process is repeated over and over, and is called the nuclear chain reaction. The nuclear chain reaction is the heart of nuclear power.

There are two important things that are released during the nuclear chain reaction. The first is heat. It is this heat that is captured and used to generate electricity.

The other thing that is released is radiation. Many types of ionizing radiation that we have discussed, include alpha, beta, gamma, and neutron radiation, are all created inside of a nuclear reactor.

In this process, we have talked about neutrons in two ways. One is in the nuclear chain reaction, and the other in neutron radiation. These two ways of talking about neutrons are in fact the same thing.
This radiation that is created inside of a nuclear power plant needs to be blocked and contained so that it cannot escape out into the surrounding environment.

In our first video, we discussed how different materials are needed to block different types of radiation. Alpha and beta radiation are relatively easy to stop, but gamma and neutron radiation are more difficult, and can penetrate more deeply into materials.
Since all of these different types of radiation are released inside of a nuclear reactor, a nuclear power plant needs to be surrounded by thick layers of concrete or water to stop the radiation from the nuclear chain reaction. This is very effective, and stops the radiation from escaping out into the surrounding environment.
Nuclear Power Safety – Other Mechanisms

- Quick shut off rods to stop the nuclear chain reaction
- Manual restart
- Emergency cooling water
- Backup power systems
- Constant monitoring from the Canadian Nuclear Safety Commission

In addition to thick shields that block radiation, there are other safety mechanisms to make sure that a nuclear power plant is safe to use and not dangerous to people nearby and the surrounding environment.

Sometimes, it might be necessary to quickly shut down a nuclear power plant. Shut off rods can be inserted into a nuclear reactor and can very quickly stop the nuclear chain reaction.

Once shut down, nuclear power plants need to be manually restarted, and cannot spontaneously start going again on their own.

Emergency cooling water systems are important to make sure that nuclear power plants do not get too hot, and backup power systems make sure that everything keeps working properly, even if electricity to the nuclear power plant is disrupted.

Finally, nuclear power in Canada is constantly monitored by the Canadian Nuclear Safety Commission. This Commission makes sure that nuclear power plants are being taken care of properly, and are not emitting radiation out into the environment. The Canadian Nuclear Safety Commissions makes sure that nuclear power used safely in Canada.

More information about nuclear power, including how we deal with nuclear waste, is available in your education booklet.
True or False Questions

1. All ionizing radiation comes from man-made sources?

2. Medical procedures such as CT scans and PET scans expose patients to ionizing radiation?

3. If an accident occurred, a nuclear power plant could explode like a nuclear bomb?

These questions are about naturally occurring and man-made sources of ionizing radiation. There are five questions in total. Pause the video to think about your answers, and then press play when you are ready to continue.
True or False Questions

4. Some areas in Canada use nuclear power to generate electricity?

5. Ultrasounds and MRIs are examples of medical procedures that use ionizing radiation.

These questions are about naturally occurring and man-made sources of ionizing radiation. There are five questions in total. Pause the video to think about your answers, and then press play when you are ready to continue.
True or False Questions

1. All ionizing radiation comes from man-made sources? False, there are many sources of naturally occurring radiation. Cosmic rays, radon gas, and radioactive atoms in food are all examples of naturally occurring radiation.

2. Medical procedures such as CT scans and PET scans expose patients to ionizing radiation? True, these types of scans expose patients to ionizing radiation. So do x-rays and mammography scans.

3. If an accident occurred, a nuclear power plant could explode like a nuclear bomb? False. A nuclear power plant cannot explode like a nuclear bomb.

These questions are about naturally occurring and man-made sources of ionizing radiation. There are five questions in total. Pause the video to think about your answers, and then press play when you are ready to continue.
True or False Questions

4. Some areas in Canada use nuclear power to generate electricity? True. Ontario has used nuclear power to generate electricity since the 1970’s. Currently, there are no nuclear power plants located in Saskatchewan.

5. Ultrasounds and MRIs are examples of medical procedures that use ionizing radiation. False. Ultrasounds use sound waves, and MRI’s use magnetism to create scans of a patient’s body.

These questions are about naturally occurring and man-made sources of ionizing radiation. There are five questions in total. Pause the video to think about your answers, and then press play when you are ready to continue.
Video #5
Comparing Different Sources of Ionizing Radiation

In this final video, we will compare how much radiation a person can be exposed to from naturally occurring background radiation, and from different sources of radiation that occur from human activities.
This figure shows a comparison of different sources of ionizing radiation that a person may encounter.
On the very left is the annual amount of ionizing radiation that we experience from naturally occurring background sources. In Regina, naturally occurring radiation is responsible for 3.5 mSv of exposure every year.

It may surprise you to see that naturally occurring radiation is one of the largest sources of ionizing radiation that we experience.
In comparison, living beside a nuclear power plant would only expose you to an additional 0.004 mSv of ionizing radiation per year. This is 875 times less than what you experience from naturally occurring sources.
You would even experience more ionizing radiation exposure from a single five-hour flight than you would by living near a nuclear power plant for an entire year.
As you can see here on the right, medical procedures can expose a person to more ionizing radiation than any of these other sources. It is important to note that the values for the medical procedures shown here, such as a mammography, CT scan or PET scan, are for a single procedures only, and do not represent annual averages like the values for natural radiation or from living near a nuclear power plants.

There is a lot of information in this picture, so feel free to pause the video for as long as you need to read all of the information. When you are ready, hit play to move on.
True or False Question

1. Most radiation that people receive on a day to day basis is from naturally occurring sources?

To check what you have learned, answer these questions about how much radiation a person could be exposed to from different sources. You can pause the video to think about the questions for as long as you like. When you are ready to continue, hit play.
Select the Best Answer

For each set of two options, select which would expose you to more ionizing radiation:

1. Total radiation from living near a nuclear power plant for one year, or a single dental x-ray?
2. Total naturally occurring radiation for one year, or a single CT scan?
3. Total naturally occurring radiation for one year, or total radiation from living near a nuclear power plant for one year?

To check what you have learned, answer these questions about how much radiation a person could be exposed to from different sources. You can pause the video to think about the questions for as long as you like. When you are ready to continue, hit play.
True or False Question

1. Most radiation that people receive on a day to day basis is from naturally occurring sources?
True. Unless you are undergoing a medical procedure such as a CT scan, most of your exposure to ionizing radiation on a day-to-day basis will be from naturally occurring radiation sources.

To check what you have learned, answer these questions about how much radiation a person could be exposed to from different sources. You can pause the video to think about the questions for as long as you like. When you are ready to continue, hit play.
Select the Best Answer

For each set of two options, select which would expose you to more ionizing radiation:

1. Total radiation from living near a nuclear power plant for one year (0.004 mSv), or a single dental x-ray (0.01 mSv)?
2. Total naturally occurring radiation for one year (3.5 mSv), or a single CT scan (10 mSv)?
3. Total naturally occurring radiation for one year (3.5 mSv), or total radiation from living near a nuclear power plant for one year (0.004 mSv)?

To check what you have learned, answer these questions about how much radiation a person could be exposed to from different sources. You can pause the video to think about the questions for as long as you like. When you are ready to continue, hit play.
Exit Questionnaire (Control Group) – This survey will be completed over the phone.

Introduction

I would just like to take this opportunity to thank you again for participating in the research project. I very much appreciate the time commitment that you made.

To complete your participation in the research, I just have a few follow-up questions that I would like to ask you. This should only take around 15 minutes to complete.

Do you wish to continue in this research project by completing this final survey?

Would you like to complete this call at another time?

*If yes, arrange time for call back.*

For any question, if you wish, you may choose to not answer that question.

For this first set of statements, please indicate if you strongly agree, somewhat agree, have a neutral opinion, somewhat disagree, or strongly disagree. Please let me know if you need me to repeat these options at any time.

For these questions, please keep in mind that there are no correct or incorrect answers.

(Q1 – Q20 Are Randomized)

2) I would accept a nuclear power plant being built in Saskatchewan. *
   1. Strongly agree
   2. Somewhat agree
   3. Neither agree nor disagree
   4. Somewhat disagree
   5. Strongly disagree
   6. Choose not to answer
3) Nuclear power is a good option to generate electricity. *
   1. Strongly agree
   2. Somewhat agree
   3. Neither agree nor disagree
   4. Somewhat disagree
   5. Strongly disagree
   6. Choose not to answer

4) The benefits associated with nuclear power exceed the risks. *
   1. Strongly agree
   2. Somewhat agree
   3. Neither agree nor disagree
   4. Somewhat disagree
   5. Strongly disagree
   6. Choose not to answer

5) Nuclear power plants are dangerous.
   1. Strongly agree
   2. Somewhat agree
   3. Neither agree nor disagree
   4. Somewhat disagree
   5. Strongly disagree
   6. Choose not to answer

6) I would be worried about living near a nuclear power plant.
   1. Strongly agree
   2. Somewhat agree
   3. Neither agree nor disagree
   4. Somewhat disagree
   5. Strongly disagree
   6. Choose not to answer

7) I can trust employees to operate a nuclear power plant safely. *
   1. Strongly agree
   2. Somewhat agree
   3. Neither agree nor disagree
   4. Somewhat disagree
   5. Strongly disagree
   6. Choose not to answer
8) Medical procedures that use radiation are dangerous.
   1. Strongly agree
   2. Somewhat agree
   3. Neither agree nor disagree
   4. Somewhat disagree
   5. Strongly disagree
   6. Choose not to answer

9) The benefits associated with medical radiation exceed the risks. *
   1. Strongly agree
   2. Somewhat agree
   3. Neither agree nor disagree
   4. Somewhat disagree
   5. Strongly disagree
   6. Choose not to answer

10) I would agree to undergo a medical procedure that involved radiation. *
    1. Strongly agree
    2. Somewhat agree
    3. Neither agree nor disagree
    4. Somewhat disagree
    5. Strongly disagree
    6. Choose not to answer

11) I would be worried about the amount of radiation I could be exposed to during a medical procedure.
    1. Strongly agree
    2. Somewhat agree
    3. Neither agree nor disagree
    4. Somewhat disagree
    5. Strongly disagree
    6. Choose not to answer

12) Medical procedures that use radiation are a good option for doctors to diagnose or treat a patient. *
    1. Strongly agree
    2. Somewhat agree
    3. Neither agree nor disagree
    4. Somewhat disagree
    5. Strongly disagree
    6. Choose not to answer
13) I can trust doctors, nurses, and medical technicians to use radiation safely during medical procedures. *
   1. Strongly agree
   2. Somewhat agree
   3. Neither agree nor disagree
   4. Somewhat disagree
   5. Strongly disagree
   6. Choose not to answer

14) It is safe to use radiation to sterilize equipment such as medical tools. *
   1. Strongly agree
   2. Somewhat agree
   3. Neither agree nor disagree
   4. Somewhat disagree
   5. Strongly disagree
   6. Choose not to answer

15) Eating food that has been exposed to radiation is dangerous.
   1. Strongly agree
   2. Somewhat agree
   3. Neither agree nor disagree
   4. Somewhat disagree
   5. Strongly disagree
   6. Choose not to answer

16) It is ok for scientists to use radiation to conduct experiments. *
   1. Strongly agree
   2. Somewhat agree
   3. Neither agree nor disagree
   4. Somewhat disagree
   5. Strongly disagree
   6. Choose not to answer

17) I am concerned about radiation exposure in my day to day life.
   1. Strongly agree
   2. Somewhat agree
   3. Neither agree nor disagree
   4. Somewhat disagree
   5. Strongly disagree
   6. Choose not to answer
18) As a society, we need to be more careful in how we use radiation.
   1. Strongly agree
   2. Somewhat agree
   3. Neither agree nor disagree
   4. Somewhat disagree
   5. Strongly disagree
   6. Choose not to answer

19) As a society, we should continue to use radiation to benefit ourselves. *
   1. Strongly agree
   2. Somewhat agree
   3. Neither agree nor disagree
   4. Somewhat disagree
   5. Strongly disagree
   6. Choose not to answer

20) As a society, we should try to find new ways to use radiation that can make our lives better. *
   1. Strongly agree
   2. Somewhat agree
   3. Neither agree nor disagree
   4. Somewhat disagree
   5. Strongly disagree
   6. Choose not to answer

21) Radiation is too dangerous for people to use safely.
   1. Strongly agree
   2. Somewhat agree
   3. Neither agree nor disagree
   4. Somewhat disagree
   5. Strongly disagree
   6. Choose not to answer

We will now move to some questions about the science behind radiation. For these questions, please just answer to the best of your knowledge.

22) First of all, how would you rate your confidence in your personal knowledge about radiation:
   1. Completely confident
   2. Very confident
   3. Moderately confident
   4. Slightly confident
   5. Not at all confident
   6. Unsure
   7. Choose not to answer
For each of the following questions, please indicate whether you believe the answer to be true or false.

(Q22 – Q37 ARE RANDOMIZED)

23) All radiation is man-made
   1. True
   2. False
   3. Unsure
   4. Choose not to answer

24) People are exposed to radioactive materials from the food we eat, the air we breathe, and in the soil around us?
   1. True
   2. False
   3. Unsure
   4. Choose not to answer

25) If exposed, all forms of radiation can cause other objects to become radioactive.
   1. True
   2. False
   3. Unsure
   4. Choose not to answer

26) Visible light, microwaves, and radio waves are examples of radiation
   1. True
   2. False
   3. Unsure
   4. Choose not to answer

27) If an accident occurred, a nuclear power plant could explode like a nuclear bomb?
   1. True
   2. False
   3. Unsure
   4. Choose not to answer

28) Saskatchewan currently uses nuclear power to generate electricity?
   1. True
   2. False
   3. Unsure
   4. Choose not to answer
29) Other provinces in Canada currently use nuclear power to provide electricity?
   1. True
   2. False
   3. Unsure
   4. Choose not to answer

30) You are exposed to radiation everyday.
   1. True
   2. False
   3. Unsure
   4. Choose not to answer

31) After being exposed to radiation in order to kill bacteria and pathogens, materials such as medical equipment or food remain radioactive?
   1. True
   2. False
   3. Unsure
   4. Choose not to answer

32) All forms of radiation are equally dangerous to human health?
   1. True
   2. False
   3. Unsure
   4. Choose not to answer

33) Most radiation that people receive on a day-to-day basis is from natural background sources?
   1. True
   2. False
   3. Unsure
   4. Choose not to answer

34) Taking an airplane flight can increase your radiation exposure?
   1. True
   2. False
   3. Unsure
   4. Choose not to answer

35) It is impossible to block radiation?
   1. True
   2. False
   3. Unsure
   4. Choose not to answer
36) Different types of radiation vary in the amount of energy they contain?
   1. True
   2. False
   3. Unsure
   4. Choose not to answer

37) Any amount of radiation exposure will cause illness?
   1. True
   2. False
   3. Unsure
   4. Choose not to answer

38) Nuclear waste from a nuclear power plant can remain hazardous for thousands of years?
   1. True
   2. False
   3. Unsure
   4. Choose not to answer

For each of the following medical procedures, please indicate if the procedure exposes a patient to radiation

(Q38 – Q42 ARE RANDOMIZED)

39) Ultrasound
   1. Yes
   2. No
   3. Unsure
   4. Choose not to answer

40) CT (computed tomography) scan
   1. Yes
   2. No
   3. Unsure
   4. Choose not to answer

41) Mammogram
   1. Yes
   2. No
   3. Unsure
   4. Choose not to answer
42) Dental x-ray
   1. Yes
   2. No
   3. Unsure
   4. Choose not to answer

43) MRI (magnetic resonance imaging) scan
   1. Yes
   2. No
   3. Unsure
   4. Choose not to answer

For the following pairs of radiation sources, please indicate which would expose you to more radiation

(Q43 – Q45 ARE RANDOMIZED)

44) Radiation from living near a nuclear power plant for one year or radiation from a single dental x-ray?
   1. Nuclear power plant
   2. Dental x-ray
   3. Unsure
   4. Choose not to answer

45) Radiation from living near a nuclear power plant for one year or total annual naturally occurring background radiation?
   1. Nuclear power plant
   2. Naturally occurring background radiation
   3. Unsure
   4. Choose not to answer

46) Total annual naturally occurring background radiation or radiation from a single CT scan?
   1. Naturally occurring background radiation
   2. CT scan
   3. Unsure
   4. Choose not to answer
I would now like you to assess the risks associated with some sources of radiation. For each of the following sources of radiation or activities, please indicate if you feel the source to be a no risk, low risk, a moderate risk, or a high risk to human health and safety.

(Q46 – Q57 ARE RANDOMIZED)

Randomize Order

47) Stored nuclear waste
   1. No risk
   2. Low risk
   3. Moderate risk
   4. High risk
   5. Unsure
   6. Choose not to answer

48) Nuclear power plants
   1. No risk
   2. Low risk
   3. Moderate risk
   4. High risk
   5. Unsure
   6. Choose not to answer

49) Radon gas
   1. No risk
   2. Low risk
   3. Moderate risk
   4. High risk
   5. Unsure
   6. Choose not to answer

50) Nuclear medicine procedures
   1. No risk
   2. Low risk
   3. Moderate risk
   4. High risk
   5. Unsure
   6. Choose not to answer
51) Cosmic radiation
   1. No risk
   2. Low risk
   3. Moderate risk
   4. High risk
   5. Unsure
   6. Choose not to answer

52) Medical x-rays
   1. No risk
   2. Low risk
   3. Moderate risk
   4. High risk
   5. Unsure
   6. Choose not to answer

53) Natural background radiation
   1. No risk
   2. Low risk
   3. Moderate risk
   4. High risk
   5. Unsure
   6. Choose not to answer

54) Taking an airplane flight
   1. No risk
   2. Low risk
   3. Moderate risk
   4. High risk
   5. Unsure
   6. Choose not to answer

55) Smoke detectors
   1. No risk
   2. Low risk
   3. Moderate risk
   4. High risk
   5. Unsure
   6. Choose not to answer
56) Nuclear weapons testing
   1. No risk
   2. Low risk
   3. Moderate risk
   4. High risk
   5. Unsure
   6. Choose not to answer

57) CT scans
   1. No risk
   2. Low risk
   3. Moderate risk
   4. High risk
   5. Unsure
   6. Choose not to answer

58) Ingestion of radioactive materials that naturally occur in food
   1. No risk
   2. Low risk
   3. Moderate risk
   4. High risk
   5. Unsure
   6. Choose not to answer

I would now like to ask you about your opinions on uses of radiation. For each of the following
options, please indicate if you strongly agree, somewhat agree, neither agree nor disagree,
somewhat disagree, or strongly disagree.

It is a good idea to use radiation for the following purposes:

(Q58 – Q63 ARE RANDOMIZED)

59) Medical diagnosis and treatments
   1. Strongly agree
   2. Somewhat agree
   3. Neither agree nor disagree
   4. Somewhat disagree
   5. Strongly disagree
   6. Choose not to answer
60) Electricity generation
1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. Choose not to answer

61) Industrial applications (such as geological surveys)
1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. Choose not to answer

62) Scientific research
1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. Choose not to answer

63) Sterilizing medical equipment
1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. Choose not to answer

64) Decontaminating food
1. Strongly agree
2. Somewhat agree
3. Neither agree nor disagree
4. Somewhat disagree
5. Strongly disagree
6. Choose not to answer

Commence debriefing script.
APPENDIX E – EXIT QUESTIONNAIRE (EDUCATION GROUP)

Exit Survey (Education Materials) – This survey will be completed over the phone.

Introduction

I would just like to take this opportunity to thank you again for participating in the research project. I very much appreciate the time commitment that you made.

To complete your participation in the research, I just have a few follow-up questions that I would like to ask you. This should only take around 15 minutes to complete.

Do you wish to continue in this research project by completing this final survey?

Would you like to complete this call at another time?

If yes, arrange time for call back.

For any question, if you wish, you may choose to not answer that question.

First of all, did you have a chance to fully read and review the education materials that were sent to you?

a. Yes
b. No
c. Choose to not answer

REMAINDER OF QUESTIONNAIRE IS AS FOR THE CONTROL GROUP IN APPENDIX D

Commence debriefing script.
APPENDIX F – PARTICIPANT DEBRIEF SCRIPT

Participant Debrief Following Exit Survey

(will occur by telephone)

Thank you again for your participation in this research.

I would like to take this opportunity to fully explain to you the research project.

My research aimed to understand how education or group interaction might impact opinions about matters that involve some aspect of science. I used radiation in Saskatchewan as my case study for this experiment. The participants in the study were separated into three groups. The first was provided with education materials about radiation. The second received the education materials and participated in a focus group. The final group did not participate in a focus group, nor did they receive education materials. This final group acted as a control.

(Indicate for the participant which group he or she was in.)

You may have noticed that the initial questionnaire you answered about your opinions and knowledge about radiation, and the final questionnaire that we just completed, had many of the same questions. This was done purposefully. By repeating questions, I hope to see what impacts, if any, the education materials or the focus groups had on the participants’ attitudes and knowledge about radiation.

This research should help us to better understand how we, as a society, come to decisions about matters that involve science. The education materials and focus groups mimic two ways that governments or other organizations might try to interact with the public on complex matters involving science.

I would like to remind you at this time that you will never be personally identified in this research. The results will be summarized and reported as summaries from all participants.

Do you have any questions?

At this time, I would like to again ask you for your permission to include your responses in my study (record date and time of consent).

If you have any questions about the research in the future, I can be contacted at [phone number] or at [email address]. The results from this research will be published in a thesis that will be available on the University of Regina’s ourSpace website. I can also provide you with the results of the research directly once they have been completed.

Take contact information from participant if requested.

Thank you for your time.
APPENDIX G – RESEARCH ETHICS APPROVAL

University of Regina

Research Ethics Board
Certificate of Approval

PRINCIPAL INVESTIGATOR
Dr. Shawn Robinson

DEPARTMENT
Johnson Shoyama Graduate School of Public Policy

REB#
2017-096

SUPERVISOR
Kathleen McNutt

TITLE
The Deficit Model and Citizen Engagement as they Apply to Radiation in Saskatchewan, Canada

APPROVED ON:
October 18, 2017

RENEWAL DATE:
October 18, 2018

APPROVAL OF:
Application for Behavioural Research Ethics Review, Telephone Survey Script, Telephone Survey, Focus Group Guiding Questions, Exit Surveys and Debriefing Script, Education Materials, Focus Group Consent Form, Focus Group and Education Consent Form

Full Board Meeting ☐ Delegated Review ☒

The University of Regina Research Ethics Board has reviewed the above-named research project. The proposal was found to be acceptable on ethical grounds. The principal investigator has the responsibility for any other administrative or regulatory approvals that may pertain to this research project, and for ensuring that the authorized research is carried out according to the conditions outlined in the original protocol submitted for ethics review. This Certificate of Approval is valid for the above time period provided there is no change in experimental protocol, consent process or documents.

Any significant changes to your proposed method, or your consent and recruitment procedures should be reported to the Chair for Research Ethics Board consideration in advance of its implementation.

ONGOING REVIEW REQUIREMENTS
In order to receive annual renewal, a status report must be submitted to the REB Chair for Board consideration within one month of the current expiry date each year the study remains open, and upon study completion. Please refer to the following website for further instructions: http://www.uregina.ca/research/for-faculty-staff/ethics-compliance/human/forms1/ethics-forms.html.

Laurie Clune, PhD
Chair, Research Ethics Board

Please send all correspondence to:
Research Office
University of Regina
Research and Innovation Centre 109
Regina, SK S4P 0A2
Telephone: (306) 585-4775 Fax: (306) 585-4893
research.ethics@uregina.ca
PRINCIPAL INVESTIGATOR: Dr. Shawn Robinson
DEPARTMENT: Johnson Shoyama Graduate School of Public Policy
REB#: 2017-096

TITLE: The Deficit Model and Citizen Engagement as they Apply to Radiation in Saskatchewan, Canada

AMENDMENT APPROVAL OF:
- Addition of Educational Video and
- Amendment of Questions # 1 – 20 in:
  - Entrance Survey
  - Exit Survey (Focus Group)
  - Exit Survey (Education Materials)
  - Exit Survey (Education Materials & Focus Group)
  - and Exit Survey (Control Group).

NEXT RENEWAL DATE: October 18, 2018
AMENDMENT APPROVAL DATE: January 10, 2018

Full Board Meeting ☐ Delegated Review ☒

AMENDMENT CERTIFICATION
The University of Regina Research Ethics Board has reviewed the changes to the above-named research project as outlined in your memo dated January 3, 2018, and they are approved.

ONGOING REVIEW REQUIREMENTS
In order to receive annual renewal, a status report must be submitted to the REB Chair for Board consideration within one month of the current expiry date each year the study remains open, and upon study completion. Please refer to the following website for further instructions:
http://www.uregina.ca/research/for-faculty-staff/ethics-compliance/human/forms1/ethics-forms.html

Ara Staininger
Research Ethics Board

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PRINCIPAL INVESTIGATOR: Dr. Shawn Robinson
DEPARTMENT: Johnson Shoyama Graduate School of Public Policy
REB#: 2017-096

TITLE: The Deficit Model and Citizen Engagement as they Apply to Radiation in Saskatchewan, Canada

AMENDMENT APPROVAL OF:
- Offering of a draw for a $100 gift card for participants who continue to participate in the research.

NEXT RENEWAL DATE: October 18, 2018
AMENDMENT APPROVAL DATE: January 18, 2018

Full Board Meeting □ Delegated Review □

AMENDMENT CERTIFICATION
The University of Regina Research Ethics Board has reviewed the changes to the above-named research project as outlined in your memo dated January 3, 2018, and they are approved.

ONGOING REVIEW REQUIREMENTS
In order to receive annual renewal, a status report must be submitted to the REB Chair for Board consideration within one month of the current expiry date each year the study remains open, and upon study completion. Please refer to the following website for further instructions:
http://www.uregina.ca/research/faculty-staff/ethics-compliance/human/forms/ethics-forms.html

Ara Steininger
Research Ethics Board

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