The Effectiveness of the Foodbot Factory Serious Game on Increasing Nutrition Knowledge in Children.

by

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Chair of Examining Committee	Dr. Manon Lemonde
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Examining Committee Member	Dr. Efrosini Papaconstantinou
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The above committee determined that the thesis is acceptable in form and content and that a satisfactory knowledge of the field covered by the thesis was demonstrated by the candidate during an oral examination. A signed copy of the Certificate of Approval is available from the School of Graduate and Postdoctoral Studies.

ABSTRACT

Background: The interactive nature of serious games (i.e., video games designed for educational purposes) enable deeper learning and facilitate behavior change; however, there is limited data on their impact on child nutrition knowledge. The objective of this study was to determine if Foodbot Factory effectively improves children's knowledge of 2019 Canada's Food Guide. **Methods:** Study was a single-blinded, parallel randomized controlled trial conducted among children ages 8-10 years attending Ontario Tech University summer day camps**. Results:** Compared to the control group (n=34), children who used Foodbot Factory (n=39) had significant increases in overall nutrition knowledge (10.3 ± 2.9 to 13.5 ± 3.8 versus 10.2 ± 3.1 to 10.4 ± 3.2, $p<0.001$), and in Vegetables and Fruits ($p<0.001$), Protein Foods ($p<0.001$), and Whole Grain Food ($p=0.040$) sub-scores. No significant difference in knowledge was observed in Drinks sub-score. **Conclusion:** Foodbot Factory is an effective educational tool to support children learning about nutrition.

Keywords: Canada's Food Guide; Serious Games; Nutrition Knowledge; Elementary School Children; Nutrition Questionnaire

AUTHOR'S DECLARATION

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I performed the majority of the synthesis, testing of the data, and writing of this thesis research. Dr. JoAnne Arcand and I took part in conceiving and designing the study. I collected, analyzed and conducted the statistical analysis of the data.

I hereby certify that I am the sole author of this thesis and that no part of this thesis has been published or submitted for publication. I have used standard referencing practices to acknowledge ideas, research techniques, or other materials that belong to others. Furthermore, I hereby certify that I am the sole source of the creative works and/or inventive knowledge described in this thesis.

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviations	**Definitions**
CFG	Canadian Food Guide
DRIs	Dietary Reference Intakes
CCHS	Canadian Community Health Survey
RCT	Randomized Controlled Trial
eHealth	Electronic Health
NAK	Nutrition Knowledge and Attitudes Questionnaire
ORBIT	Obesity-Related Behavioural Intervention Trials

GLOSSARY

Serious Games	Video games designed for education
Gamification	Use of game design elements in non-game contexts
Behaviour Change Techniques	Components that alter and enable behaviour change through engaging features that promote motivation and the desire to learn

CHAPTER 1.0: INTRODUCTION

Nutrition is crucial for early childhood growth and development. A high quality diet during this time period can also reduce the risk of chronic diseases and impact overall long-term healthy eating behaviours (Health Canada, 2020). There are various factors that influence the dietary intakes of healthy nutrients in children (Haines et al., 2019). Nutrition knowledge, food literacy, and food skills, have been positively associated with a greater understanding and interpretation of nutrition information in the complex food environment (Health Canada, 2019g). Implementation of nutrition education interventions early in childhood have the potential to increase nutrition knowledge, and improve their dietary intakes during childhood and throughout the lifespan (Health Canada, 2019g).

Multiple public health and school-based interventions exist to educate Canadian children about nutrition and healthy eating. The revised Canadian Food Guide (CFG) is an example of a public health intervention aimed to provide Canadians with the most updated evidence-based nutrition information to make appropriate healthy eating choices. However, the majority of the CFG content is online, and is missing essential engaging components such as gamification and behavior change techniques that can benefit child learning. Additionally, nutrition education is a core component of the elementary school curriculum, and has been effective in improving child nutrition knowledge and diet quality (Dudley, 2015). An emerging and promising way to deliver nutrition education and enhance long-term retention of information and behavior change, are the use of evidence-based digital interventions, specifically those that involve serious games. (Zarnowiecki et al., 2020)

Existing studies on the effectiveness of serious games on nutrition outcomes, have shown that serious games may increase consumption of vegetable and fruit intake, decrease consumption in sugar-sweetened beverages, and nutrition knowledge (DeSmet et al., 2014; Hermans et al., 2018; Holzmann, Schäfer, et al., 2019; Majumdar, 2013; Nollen et al., 2014). Despite these positive results, and the emerging use of serious games used as interventions to improve child nutrition knowledge and behavioural outcomes, there are no known evidence-based serious games that exist to support nutrition knowledge for Canadian children, and to improve dietary intakes of all the food groupings in the CFG. Additionally, there is no known evidence of a serious game implemented into the Canadian elementary school curriculum.

To address these gaps, Foodbot Factory was designed by a team of experts in nutrition sciences, dietetics, game development/computer science, and educational pedagogy and technology, at Ontario Tech University. Foodbot Factory aims to improve nutrition knowledge in children by teaching key messages related to healthy eating choices in the CFG and following the Ontario elementary school curriculum. Foodbot Factory contains gamification elements and behavioural change techniques including feedback and monitoring, social support, shaping knowledge, natural consequences, reward, and threat, quizzes and sub-games requiring a user to catch food and sort food all which are key features that provide highly engaging learning experiences and can result in higher motivational learning, academic achievement and knowledge (Abramovich, 2013; Dicheva, 2015; Dunn, 2018; Hswen, 2013; Morrison, 2014). Foodbot Factory has undergone extensive testing with children as part of the development and evaluation process, as described by the Obesity Behaviour Research Trials (ORBIT) model (Brown et al., 2020). However, Foodbot Factory has not been evaluated in a more representative group of children or tested against a control group. Therefore, the objective of this thesis is to evaluate the effectiveness of Foodbot Factory in increasing children's nutrition knowledge, and additionally in supporting children's learning about Canada's Food Guide.

CHAPTER 2.0: LITERATURE REVIEW

1.0. The Importance of Nutrition in Childhood

1.1 Importance of a Nutritious Diet

Nutrition is a key element for healthy human growth and development and can reduce the risk of chronic diseases and promote positive academic performance in children (Health Canada, 2020; Kim & Kang, 2017). A nutritious diet and healthy eating habits are especially crucial for the early childhood years, as it can impact overall long-term health and healthy eating behaviours throughout the lifespan (Health Canada, 2020). High diet quality occurs when one's eating patterns include adequate nutrient and energy intake to meet the nutritional needs of the individual. High diet quality is achieved by making heathy eating choices such as consuming a variety of vegetables and fruits, whole grain foods, protein foods and limiting highly processed foods that are high in sodium, saturated fat and sugar (Haines et al., 2019; Health Canada, 2019f).

In the early developmental period, nutritional needs are high, requiring high quality foods such as vegetables and fruits, whole grains, healthy fats and healthy sources of protein, all of which can affect cognitive performance and academic achievement (Burrows, Goldman, Pursey, & Lim, 2017). Findings from a systematic review (n=33) including children 5-18 years showed that a higher fruit and vegetable intake is associated with higher academic achievement such as Grade Point Average (Burrows et al., 2017). Multiple studies have found that increased intakes of folate, iron, energy, protein, B vitamins, and omega 3 fatty acids are positively associated with academic achievement and test scores (Aquilani, 2011; Hulett, 2014; Ivanovic, 2013; Nilsson, 2011). In contrast, another study of over 12,000 fifth graders found that a higher intake of fast food multiple times a week (four to six times in the last seven days or more) was associated with lower reading scores in children (Tobin, 2013). Consuming whole grains, vegetables and fruits, plant and animal proteins can decrease the risk of cardiovascular disease, cancers and infectious disease, stroke and type 2 diabetes, and lower blood pressure in individuals of all age groups (Angelino et al., 2019; Heart and Stroke Foundation, 2013; Kyrø & Tjønneland, 2016; Song et al., 2016). In contrast, poor diet quality may adversely impact growth and development, reduce cognitive function and academic achievement or performance, and increase the risk of obesity and chronic disease (Hurley, 2016). The prevalence of overweight and obesity in Canadian youth ages 6 to 11 is 25.8%, and 36.8% in ages 12 to 17 years (Rao, 2016). Overweight and obesity leads to a higher risk of children being diagnosed with type 2 diabetes, high blood pressure, high cholesterol and metabolic syndrome (Pulgaron, 2014; Rao, 2016). Obesity can also lead to emotional health problems such as low self-esteem, negative body image, depression, and the onset of chronic diseases (Health Canada, 2019c; Roberts, Shields, de Groh, Aziz, & Gilbert, 2012). Therefore, early childhood nutrition interventions are considered a highly effective way to improve the quality of the dietary intakes of children to benefit health outcomes later in life (Macaulay et al., 2014).

1.2 Dietary Intakes of Canadian Children

The Dietary Reference Intakes (DRIs) are used by Health Canada to evaluate how well Canadians are eating, and to ensure that public health recommendations are based on evidence (Health Canada, 2019e). In 2004 and 2015, Statistics Canada carried out a nationally representative dietary survey using 24 hour recalls as part of the Canadian

Community Health Survey (CCHS). This data forms the basis of what is known about dietary intakes of Canadian children at a national and provincial level.

Whole grains foods currently contribute 17% of total daily intakes of grain products, with the highest mean daily intake of grain products being among Canadian children and adolescents (Tugault-Lafleur & Black, 2019). From the 2004 to the 2015 CCHS survey, consumption of grains among children ages 2-5 and 6-12 increased by +0.7 servings/day (Tugault-Lafleur & Black, 2019); however, these changes are largely due to increased intakes of refined grain foods (Tugault-Lafleur & Black, 2019).

Intake of vegetables and fruits in children aged 2 and older was 5.2 servings/day which was significantly lower in 2015 (-0.7 servings/day) compared to 2004 (Tugault-Lafleur & Black, 2019). Additionally, Canadians in all age groups consumed significantly more protein foods (+0.2 servings/day), with higher intakes of legumes, nuts and seeds (+0.1 servings/day) in 2015 compared to 2004 (Statistics Canada, 2018; Tugault-Lafleur & Black, 2019). Canadian children receive 15.6% of their daily energy intake from proteins (Tugault-Lafleur & Black, 2019). This data shows that plant protein intakes are increasing in Canada, which is a positive change as plant proteins offer nutritional benefits that are linked to a high source of vitamins, minerals and dietary fiber, and aligns with the CFG (Ahnen, 2019)

While consumption of water increased from 2004 to 2014, intake of sugary drinks, alcohol and milk continue to substantially contribute to Canadians overall energy intakes (Jones, Kirkpatrick, & Hammond, 2019). Sugary drinks, which are drinks containing free sugars such as honey, syrups, and fruit juices, contribute to overall energy density of beverages (Jones, Veerman, & Hammond, 2017; World Health Organization, 2015).

Sugary drinks contribute 44% of sugar intakes in children and adolescents aged 4 to 18 years of age, and the highest sugary drink consumption continues to be seen among children, who are the highest consumers of 100% juice and other sugary drinks (Jones et al., 2019; Tugault-Lafleur & Black, 2019). Individual's total intake of sugars should not exceed 10% of total daily calorie intake (2000) as intakes are associated with the risk of excess body weight, heart disease and obesity in both children and adults (Heart and Stroke Foundation, 2014; Malik, 2013; Te Morenga, 2013; Tugault-Lafleur & Black, 2019). The average intake of fruit juices was highest among children in the 2015 survey, with 1.0 servings/day (Tugault-Lafleur & Black, 2019).

Despite the importance of these nutrients, children may get confused about the nutrition information being presented in the food environment. For example, a study found that children described "kids food" as unhealthy, colourful and sugary, whereas adult food was found to be boring, plain, fruits and vegetables, proteins, and foods that contain no fat or sugar (Elliot, 2011). Additionally, children do not always control what they eat and there are various factors that impact their food consumption including positive parental feeding and having a healthy home food environment (i.e., encourage healthful food choices by ensuring nutritious foods are available) (Haines et al., 2019).

1.3 Factors that Impact Children's Nutrition Behaviours

As children's dietary patterns begin in childhood and food preferences change throughout life, it is necessary to identify the influences, such as school environment, peers and parental guidance, that affect children's dietary behaviours (Gates, 2013; Public Health Ontario, 2013; Russell & Worsley, 2013; Upitis, 2013). During childhood, the family is the key factor and play a dominant role in establishing food preferences and eating habits (Scaglioni, 2018; Vollmer, 2013). While parental influences on children's nutrition knowledge is not often mentioned in existing studies, an increase in parental nutrition knowledge and attitudes is positively associated with healthier eating practices in children such as consuming fruits and vegetables (Hendrie, Sohonpal, Lange, & Golley, 2013). Additionally, positive parental feeding, eating together, positive home food environment, and the pleasure of eating and encouraging healthy eating practices at home are all themes that were also identified to play key roles in the development of healthy eating habits in children (Haines et al., 2019). One review, in which parenting styles described by the authors as authoritative, authoritarian, permissive, and neglectful, highlighted the importance of parenting style on child dietary intakes (Vollmer, 2013). According to the author, an authoritative parenting style (high demandingness, high responsiveness), was positively associated with a higher fruit and vegetable intake and beverage consumption (Hennessy, Hughes, Goldberg, Hyatt, & Economos, 2012; Vollmer, 2013). In comparison, neglectful parenting styles (low demandingness, low responsiveness) have been negatively associated with fruit and/or vegetable intakes, and with high fat and sugar intake (Hennessy et al., 2012; Vollmer, 2013).

Peer relationships also influence decision-making and food consumption choices. A recent systematic review found that 12 of 29 studies identified significant associations between a peers influence on eating behavior, with peers enabling an increase in the consumption of low-nutritional value foods (Rageliene, 2020). While there are various factors that affect nutrition and eating behaviours, there is also a role for nutrition knowledge to provide children with the opportunity and food skills; has the information, ability, and practices to acquire and prepare nutritious foods to make their own healthy eating decisions (Health Canada, 2019g).

1.4 Nutrition Knowledge of Children

Nutrition knowledge and food skills support children in making lifelong healthy eating decisions and in navigating complex food environments (Health Canada, 2019g). As children grow and gain independent in food choices, food skills provide individuals with the knowledge on how to evaluate and interpret nutrition information to make healthy eating choices (Health Canada, 2019g). Many of the health risks identified in children's eating habits can be addressed by increased nutrition knowledge, food literacy and food and nutrition education (Henderson, 2011; Public Health Ontario, 2013). The importance of nutrition education, knowledge, food literacy, and food skills has been emphasized by Health Canada's Healthy Eating Strategy (Health Canada, 2016) and Canada's Dietary Guidelines (Health Canada, 2019b). Nutrition knowledge provides the foundation for healthy eating habits and behaviours, and intervening early in children's health, education and development has benefits that can be applied throughout the child's lifetime (Clark et al., 2020).

According to a Food Literacy Framework, there are five components to food literacy: nutrition knowledge, food skills, self-efficacy and confidence, food decisions, and external factors such as socio-cultural influences and socio-economic status (Locally Driven Collabative Project Team, 2017). These components are recognized as important influences on eating patterns and long-term behavior (Locally Driven Collabative Project Team, 2017). Higher levels of nutrition knowledge in children have been positively associated with a greater intake of highly nutritious food such as vegetables and fruit, and whole grain foods (Asakura, Todoriki, & Sasaki, 2017; Noronha et al., 2020). Additionally, children whose teachers and caregivers have more nutrition and food training have higher levels of nutrition knowledge, compared to teachers and caregivers that have not received any training (Korzun, 2014). As children spend most of their day at school, this can provide positive learning environments and role models such as teachers, to support healthy behaviours (Korzun, 2014). Additionally, multi-component nutrition programs that are implemented in Canadian elementary schools, have been positively associated with children's development of nutrition knowledge, dietary behavior changes, and intake of healthy foods (Colley, 2018). Despite the inclusion of nutrition as part of the Canadian school curriculum (Ontario Curriculum, 2019), an understanding of children's use of nutrition information to assess food environments and make food decisions is minimal. There is limited literature on what exactly Canadian children know about nutrition and whether they apply their learned knowledge in real-world settings. As there are various conflicting messages within the food environment; such as commercial messages marketing foods high in sodium, sugar, salt and fat, it is important to understand how children use knowledge to navigate the food environment (Health Canada, 2016).

While little is known about nutrition knowledge in Canadian children, some research has been conducted on this topic in other countries. In the United Kingdom, students' knowledge increased with age, and increased knowledge was associated with a preference for fruits and vegetables (Bonsmann, 2014). The level of nutritional knowledge has been impacted by the type of school students attended. For example, in

Germany higher nutrition knowledge was positively related to schools with higher academic success rates (Schultz & Danford, 2016). Another study administered a 43 item questionnaire (4 nutrition questions) to 293 children (Holzmann, Dischl, et al., 2019). Overall, only 5.5% of participants correctly answered all 4 nutrition knowledge questions and 22.8% of participants knew that eating fruits and vegetables 5 times per day is recommended (Holzmann, Dischl, et al., 2019). These findings are consistent with another study that found 50% of German children and adolescents have inadequate knowledge of the components of a healthy diet. Despite nutrition education and policies being implemented in European schools such as Spain, Switzerland, Portugal, and Ireland (Weichselbaum, 2011), childhood obesity is also on the rise in Europe, and there is still low nutrition knowledge among children, globally (Hamulka, Wadolowska, Hoffmann, Kowalkowska, & Gutkowska, 2018)

2.0. Efforts to Improve Nutrition Knowledge, Attitudes and Behaviours among children

2.1 Public Health Interventions to Support Nutritional Health in Children

Effective policies at federal, provincial and municipal levels are essential to promote healthy eating and to create healthy food environments to improve nutrition outcomes (Bacon, 2019). Canada's Healthy Eating Strategy is an example of a public health strategy that proposes multiple interventions to improve the food environment in Canada (Health Canada, 2016). One of the most crucial elements under Canada's Healthy Eating Strategy is the revised online 2019 CFG. Disseminated in an online-first format, with the majority of the CFG published on the Health Canada website, the revised CFG provides dietary guidance based on the most updated scientific evidence (Health Canada, 2019b). The CFG provides guidance to Canadians related to healthy eating choices, on foods and beverages that undermine healthy eating, and on food habits (Health Canada, 2019b). At a provincial level, health programs have been implemented, such as the Healthy Kids Community Challenge in Ontario, that aims to promote healthy behaviors in children up to 12 years across 45 communities by developing activities, addressing provincial support and short-term community and individual outcomes (Public Health Ontario, 2020). These are essential public health tools that can be used as health promotion strategies for shaping children's nutrition knowledge and attitudes, and food skills (Craigie, Lake, Kelly, Adamson, & Mathers, 2011; Forneris et al., 2010; Health Canada, 2019b). However, despite the CFG being an essential intervention to be used in elementary schools to teach children about nutrition, the majority of the CFG content is online and not child focused, and there is a lack of tools available to help educators and children teach and learn about the CFG in elementary schools.

2.2 School-based Interventions

In Canada, nutrition education is a core component of the elementary school health curriculum (Korzun, 2014). Across Canadian provinces, the nutrition curriculum is a core policy as children in grades 1-8 learn various nutrition skills such as identifying factors that influence healthy choices, the sources of major nutrients and their functions, the recommended daily servings of nutrients, and Canada's Food Guide (PHE Canada; Saskatchewan Health Authority, 2017). In Ontario specifically, nutrition curriculum in schools aims to support students in developing the necessary knowledge and skills to become informed about the food environment (Ontario Curriculum, 2019; The Ontario

School Food and Beverage Policy, 2011). The Ontario elementary school guidelines support at least 50 hours of nutrition education in elementary schools on topics such as nutrition literacy, food and nutrition, the CFG, and enough scientific facts for children to understand food, nutrition and health such as nutrients, healthy eating choices, the nutrition facts table and food labels and media influences (Colley, 2018; Ontario Curriculum, 2019; Schultz & Danford, 2016). A systematic review (n=11 studies) concluded that multi-component (i.e., policies, education, and family and community involvement, Canadian school nutrition programs) programs were positively associated with children's development of nutrition knowledge, dietary behavior changes, and intake of healthy foods (Colley, 2018). As Canadian school nutrition programs support nutrition education, this can enhance skills for children to make healthy dietary decisions (Critch, 2020; McKenna, 2010). There is little published literature on how nutrition education is delivered in classrooms. However, there may be a role for technology in nutrition education with increasing use and availability to teach in classrooms.

2.3 Digital Interventions to Improve Nutrition Knowledge, Attitudes and Behaviours among children

The rising use of digital technologies and serious games as a health intervention strategy is emerging in public health and nutrition education. Well-designed evidence-based digital interventions that incorporate engaging game-based learning via serious games (i.e. video games designed for education) may provide children with a fun and enjoyable learning experience and improve knowledge and behaviours, (Shute, 2009; The Lancet Digital Health, 2020). Existing studies have shown positvie results on the effectiveness of digital devices and serious games on nutrition knowledge and behaviour outcomes in children and adolescents, such as fruit and vegetable consumption, and/or intake of processed snacks (Baranowski, Ryan, Hoyos-Cespedes, & Lu, 2019; Holzmann, Schäfer, et al., 2019; Nollen et al., 2014). This is of particular importance as there is an increasing amount of access to digital technology at home and within the elementary school environment. Despite this, there is limited research on the effectiveness of digital interventions and serious games on improving nutrition knowledge and behaviours/attitudes of specific nutrients among children, and currently no technology-based tools and resources that have been broadly implemented in Canada to teach children about the CFG.

2.4 Access and Use to Digital Devices: Children

2.4.a At Home

Digital devices are increasingly common within Canadian households. A recent report showed that the majority of Canadian households with children 18 years or younger (98%) have access to internet and digital tools at home (Frenette, Krank, & Deng, 2020). A survey conducted in 2014 on Canadian children (n = 5,400) in grades 4-11 found that the majority of children had their own cellphone (Oliveira, 2014). In this survey, nearly one in four of the younger children own a mobile device, and 59% of children regularly play games on their mobile device (Oliveira, 2014). From a young age, children's parents begin to manage their children's mobile device use (screen time), which may have an effect on their use of digital tools within the home (Livingstone, Mascheroni, Dreier, Chaudron, & Lagae, 2015). The 2014 survey conducted on children in grades 4-11 (n = 5,400) found that 84% of the children had parents with at least one rule concerning digital app and online use (Oliveira, 2014). Socio-economic status is another factor that may affect children's access to digital devices within the household. Canadians with higher incomes have more access to digital tools (95%), compared to those with low incomes (62%) (College Libraries Ontario, 2020). Additionally, students in rural communities have more limited access to computers or the internet at home, compared to those in urban areas (People for Education, 2019). Canada faces a national connectivity gap as only 37% of rural communities have access to reliable internet, compared with 97% of urban Canadian homes having access to reliable internet (Government of Canada, 2019; People for Education, 2019). The People for Education Canadian Organization aims to address this gap by creating evidence dialogue and in building links towards a promise of public education (Education, 2021). Additionally, in 2019 the federal government committed to $1.7 billion over 13 years to work towards providing high-speed internet throughout Canada (People for Education, 2019).

In Ontario, 33% of elementary schools report that students are encouraged to bring their electronic devices from the household to use every day in the classroom (People for Education, 2019). However, among schools that encourage bringing your own device into the classroom to support digital learning, less than half of the students participated, particularly in low income neighbourhoods where families may not have access to technology at home (People for Education, 2019). To reduce the digital divide between students, policies and interventions need to be implemented into other environments; such as elementary schools, where children spend the majority of their day and are able to gain access to these educational digital tools.

2.4.b Within Schools

To bridge the divide between students who may not have access to digital tools at home, government investments have helped schools acquire, and increase student access to, digital technology and learning tools for disadvantage students (Ministry of Ontario, 2020). The use of digital tools to deliver education is becoming a norm in elementary schools. Currently, 97% of Ontario elementary schools report at least some teachers using technology to communicate with students, and with the proper professional development, technology can be an effective teaching tool within the classroom (Fullan, 2014; Heart and Stroke Foundation, 2013; People for Education, 2019). As children may not have access to digital tools at home, school settings are a highly strategic way to expand and accelerate learning about nutrition and healthy eating (Fullan, 2014; Heart and Stroke Foundation, 2013). Digital learning helps students work collaboratively, develop problem solving, critical thinking and creativity skills, while increasing motivation and ownership of learning (People for Education, 2019). Currently, the importance and opportunities of using technology for education was highlighted among school closures globally amid the COVID-19 pandemic, with children learning (and some will continue learning) at home via online classrooms (Ministry of Ontario, 2020). The Ontario Minister of Education has recently announced a $15 million purchase for computers to help ensure students return to school among the COVID-19 pandemic with the tools they need to succeed within the classroom (Ministry of Ontario, 2020). The enhanced integration of technology in the classroom is an opportunity to implement serious games as digital educational interventions in primary school settings to teach children about nutrition.

2.5 Effectiveness of digital interventions and serious games at improving nutrition Knowledge and behaviours/attitudes

2.5.a The Importance of Digital-Interventions

In health promotion, there is a shift away from the use of paper pamphlets to the use of online sources of information and digital interventions to reach a broad range of diverse consumers and populations (Pollard, Pulker, Meng, Kerr, & Scott, 2015). Digital interventions can include those that use the internet, mobile applications, websites, smartphone apps, and text messaging services, (Bradbury, Watts, Arden-Close, Yardley, & Lewith, 2014). The use of technology can address challenges related to student motivation and engagement, as traditional schooling is sometimes perceived as ineffective and boring to many students who are used to digital tools (Dicheva, 2015). Traditional teaching styles differ from interactive student-centered learning through technology, since technology shifts the focus of the instruction from the teacher to the student, and the student develops autonomy and independence by making themselves responsible for their own learning path (Hendriks, 2016). However, despite the increase in technology within the classroom, there is limited literature on the effectiveness of digital tools within the school environment related to nutrition education. According to a systematic review, 22 studies were identified out of 155, that evaluated digital tools as a school-based intervention that assessed consumption of fruits and vegetables (n=9), and consumption of sugar-sweetened beverages or snacks (n=4) (Champion, 2019). A limitation in this systematic review is the lack of literature that assessed school-based digital interventions. This could be due to school policies (i.e., prohibiting the use of mobile phones in the classroom), or the systematic review eligibility criteria which required interventions to be primarily delivered via e-health (Champion, 2019). The results of this study show that further research needs to be conducted on the effect of digital tools within the school environment, specifically on serious games. Despite the changing policies of digital interventions being implemented into elementary schools, the use of these digital tools for elementary school students has not yet been fulfilled in the literature (Champion, 2019; People for Education, 2019). This is an excellent opportunity to implement digital interventions, specifically serious games, into the elementary school environment for children.

Various studies portray positive findings related to the effectiveness of digital interventions as tools to increase nutrition knowledge and behaviours. Findings from a meta-analysis (n=12 studies) found that student learning outcomes in multiple courses such as science, social studies, and mathematics, can improve when learning with technology such as tablets (n=9 studies with positive learning outcomes) (Habler, 2015). Another systematic review examined the impact of digital interventions on nutrition-related behavioural outcomes including 26 studies on digital interventions which consisted of websites (n=15), text messages (n=4), games or apps (n=3), email (n=1) and social media (n=1), and three being multi-component interventions (Rose, 2017). This systematic review concluded that digital interventions can positively affect diet (consumption of vegetable and fruit intake and sugar sweetened beverage) and physical activity behavior change amongst adolescents, however, diet was only evaluated in two of the studies and the observed positive effects were typically not sustained long-term (Rose, 2017). While the magnitude of the impact between each of the digital interventions vary, small effects were observed to be statistically significant within studies (Baranowski et al., 2019; Lappan, Ming-Chin, & Leung, 2015; Lau, Lau, Wong del, & Ransdell, 2011; Nollen et al., 2014; Smith, 2014). However, those studies include a variety of technologies. As mobile applications are emerging as health promotion interventions and becoming popular both in the household and the school environment, this provides an opportunity to use these applications as educational tools for children to learn about nutrition and healthy eating.

Mobile applications are an increasingly common form of digital intervention, including food and nutrition themed apps. A survey conducted on the use of mobile applications by Canadians, found that 68% of Canadians download and use apps, and 26% of mobile user's access health and wellness tools through their devices such as calorie counters (16%) and fitness or exercise trackers (11%) (Ho, 2013). However, there is a lack of nutritional applications that are evidence based and educational. The results of an environmental scan of food and nutrition themed child apps (n=142 food apps) available on the Canadian marketplace found that fruits were more frequently used than vegetables (61% vs 44%) in food games, however fruits were mostly shown with sweet foods such as desserts, chocolates and candy (55%), and only a small number of food apps that had fruits on its own without sweet and sugary foods (7%) (Brown, Siddiqi, Froome, & Arcand, 2019). Additionally few apps included whole grains (4%), plant-based proteins (10%), or fish (14%), and there was no application that directly provided nutrition information, with only a small percentage of apps including healthy eating messages (3%) (Brown et al., 2019). This recent search aligns with another systematic scan of child nutrition apps which found more diet apps rather than nutrition apps (76%

vs 66%) in the Google Play Store (Schumer, Amadi, & Joshi, 2018; Zarnowiecki et al., 2020). While there is a lack of educational nutrition apps for consumers, further research on the effectiveness of mobile apps; specifically on serious games, is needed in the literature.

2.5.b The Potential of Serious Games for Nutrition Education

Serious games are video games used for education and are often available as an app on a mobile device. Serious games are educational interventions that can be applied in non-gaming (e.g. personal development, school, businesses) contexts, and contain engaging and enjoyable characteristics such as gamification and behavior change techniques (BCTs) to promote learning (Baranowski et al., 2019; DeSmet et al., 2014; Deterding, 2011; Lewis, Swartz, & Lyons, 2016). Gamification is defined as the use of game design elements in non-game contexts, and BCTs are defined as a component of an intervention designed to alter and enable behavior change through engaging features that promote motivation and the desire to learn (Carey et al., 2019; Deterding, 2011). The Behaviour Change Technique Taxonomy v1 is an extensive taxonomy of 93 agreed, distinct BCTs that offers a method for specifying and identifying reliable components of interventions that elicit behaviour change (Michie et al., 2013). Additionally, the Taxonomy of Gamification concepts for health apps contributes to an understanding of gamification concepts and their characteristics within applications (Schmidt-Kraepelin, Thiebes, Tran, & Sunyaev, 2018). Examples of gamification techniques that have been proven to work in digital health behaviour change interventions such as feedback and monitoring, social support, shaping knowledge, natural consequences, reward and threat, quizzes, and sub-games (Brown et al., 2020; Schmidt-Kraepelin et al., 2018). These gamification and behaviour change techniques promote nutrition learning in fun and engaging ways, and is a promising way to motivate children in educational settings. Within the school environment, the implementation of technology; specifically serious games, has the potential to enable, expand, and accelerate learning, and allow students to develop problem solving and creativity skills (People for Education, 2019). As there is existing literature on the effectiveness of serious games to increase nutrition knowledge and outcomes in children, it is important to understand what essential components of serious games make them effective digital learning tools for children.

2.5.c A Theoretical Basis for Serious games

Based upon and supported by a theory of motivation called self-determination theory, serious games engage the user extrinsically (based on rewards, avoiding punishments, etc.) as oppose to relying solely on intrinsic motivation (engagement due to interest) (Ryan, Rigby, & Przybylski, 2006; Uysal & Yildirim, 2016). According to self-determination theory, serious games promote user satisfaction and enhance learner motivation, which can enhance children's educational experiences (Roberts., 2017). The use of serious games also addresses psychological needs to support motivation and well-being, such as promoting autonomy; willingness when completing a task, competence; feeling capable of achieving desired outcomes, and relatedness; feeling understood and connected with others (Rigby, 2011; Ryan et al., 2006; Uysal & Yildirim, 2016). Serious games that include all three of these needs, are successful in enhancing satisfaction and motivation (Rigby, 2011; Ryan et al., 2006; Uysal & Yildirim, 2016). The top two most effective and statistically significant behaviour change principle and techniques within gamification strategies include goal setting and the capacity to overcome challenges, alongside providing feedback on performance, reinforcement, comparing progress, social connectivity and fun and playfulness (Cugelman, 2013). Due to these key components, serious games provide a promising venue for engaging participants in increasing nutrition knowledge and outcomes, and dietary behaviour changes.

2.5.d A Summary of Existing Serious Games for Children

The positive impact of serious games on nutrition outcomes has been documented in several studies (Appendix 1). These single studies have shown that serious games were effective in increasing consumption of fruits and vegetables and decreasing consumption of sugary drinks. The majority of the existing research on serious games found have been empirically evaluated through quasi-experimental and RCT study designs, ranging in duration from two and three days to six months, with the intensity of the intervention ranging from 15 to 50 minutes (Holzmann, Schäfer, et al., 2019; Johnson-Glenberg, 2014; Thompson et al., 2015). These existing studies targeted dietary behaviours such as intakes of fruits and vegetables and have found a significant positive impact on nutrition attitudes, fruit and vegetable consumption, and a decrease in frequency of unhealthy snacks and sugar-sweetened beverages (Majumdar, 2013; Thompson et al., 2015). All existing serious game interventions contained engaging elements for behaviour change, such as feedback, challenges, story narratives, and rewards. Despite the positive results of the existing studies on serious games, most of the effects of nutrition knowledge were short-term and were not maintained over time. Additionally, majority of the studies identified did not measure intakes of other primary nutrients such as whole grain foods and proteins, and no serious game was found that identified the key messages of the 2019

CFG. Detailed impacts of serious games on nutrition knowledge, attitudes and behaviours are described in the following sub-sections.

2.5.e Impact of Serious Games on Nutrition Behaviours

The positive impact of serious games on nutrition behavioural outcomes has been documented. Systematic reviews have shown that serious games were effective in increasing consumption of fruits and vegetables, and decreasing consumption of sugary drinks; however majority of the studies identified were in adults, not children, and were not conducted within school environments (Champion, 2019; Chow, 2019; Schoeppe, 2016; Villinger, 2019). Additionally, two single studies that tested the effectiveness of serious games on behaviours found a significant positive impact on nutrition attitudes, fruit and vegetable consumption, and a decrease in frequency of unhealthy snacks and sugar-sweetened beverage intake (Majumdar, 2013; Thompson et al., 2015). These two studies targeted dietary behaviours such as intakes of fruits and vegetables, and contained engaging elements such as feedback, and rewards. Despite the positive results of the existing studies, only short-term significant effects were found in the consumption of fruits and vegetables, and/or intake of processed snacks.

A scoping review of studies examining serious games on nutrition education for children (n=22 articles) found that all contained engaging elements such as a story or narrative (Baranowski et al., 2019). Overall, 59% of serious games targeted children in schools with most studies in this review reported positive impacts on nutrition knowledge, fruits and vegetables consumption, and/or intake of processed snacks (Baranowski et al., 2019). However, it should be noted that the observed effects on behaviours were either small or were not maintained over time. Additionally, the content of the serious games is mainly focused on the dietary behaviours related to the consumption of vegetables and fruits and sweetened beverages and excluded other healthy foods and nutrients such as whole grain foods and plant-based protein foods. As there is limited games that contain content that focus on other important foods and nutrients, it is unknown that serious games can facilitate broader dietary changes to diet. Despite the existing research conducted on the effects of serious games on nutrition knowledge and behavioural outcomes in children, there is limited literature of serious games related to Canadian dietary guidelines and within the school environment. To our knowledge, there is only one existing study of a serious game that will be implemented in Canada with integrated gamification using games, quizzes and tasks, to measure lifestyle behaviours, that includes a goal of (improving dietary quality) among youth 12 years and older (Mâsse et al., 2020). However, a limitation of this app is that nutrition education is not the primary objective, rather it is one of four main health behaviours of interest that also include physical activity, screen time, and sleep behaviours (Mâsse et al., 2020). Despite the positive findings of serious games and nutrition behaviours, many of these games observed within the studies were not digital (i.e., board games) (Skouw, 2020; Viggiano et al., 2015), and dietary knowledge and intake were measured through self-reported methods, such as dietary recalls, food records, and questionnaires, which may lead to under/over-reporting of these outcomes. These gaps highlight an important opportunity for the development, implementation, and evaluation of a serious game in Canada to promote nutrition education and improve dietary intakes on all essential food. However, besides nutrition behaviours, the effect of serious games on nutrition knowledge is even further limited within the published literature.

2.5.f Impact of Serious Games and Knowledge and Attitudes

Adequate knowledge is a prerequisite for making healthy eating choices. Existing literature has been available in the context of serious games and knowledge acquisition in children (Holzmann, Schäfer, et al., 2019; Johnson-Glenberg, 2014; Schneider, 2012). One experimental study was conducted among 108 elementary school children to play the nutritional game 'Alien Health Game' (AHG) (Hermans et al., 2018). Participants who played AHG had significantly greater improvements in macronutrient nutritional knowledge (Baseline knowledge 1.11/5 points, 4.45/5 points post-test, $p = 0.001$ immediately post-test). However, this effect was only maintained for the intervention period and after two weeks and there was no evidence for behaviour change. Systematic reviews and meta-analysis have examined serious games for children and have shown that serious games increase short and long term knowledge (Chow, 2019; DeSmet et al., 2014; Girard, Ecalle, & Magnan, 2013). These studies show that the implementation of serious games have the potential to become novel educational interventions to improve nutrition knowledge in an intrinsically motivating format. Serious games that have been empirically evaluated, have intervention periods that ranged in duration from three days to six months, with the longest measure of nutrition knowledge was three years (Del Río et al., 2019; Thompson et al., 2015). Within this latter study, knowledge in the experimental group increased over the long-term from 27.00 (3.64) at baseline to 30.87 (2.95) follow-up at 3 years ($p<0.001$) (Del Río et al., 2019). Importantly, current serious games on nutrition education for children are mainly focused on the dietary knowledge and behaviours related to the consumption of vegetables and fruits. Therefore, there is a need for such games to incorporate other nutritional concepts such as whole grain foods, protein foods, and water, as well as children’s eating attitudes and behaviours to offer children a comprehensive understanding of nutrition. Moreover, data on the long-term effects of serious games, including retention of dietary knowledge and behaviours among children, specifically within elementary school settings, is limited and must be explored with future research. As public health interventions, such as the CFG, aim to improve nutrition knowledge, there are currently no existing digital tools in Canada to assist educators and students in learning about the key components of the CFG. The development and implementation of a serious game within the elementary school environment will address the gap in the literature on the limited knowledge on the effectiveness of digital serious games on nutrition knowledge within the school environment.

3.0. Foodbot Factory

3.1 Overview of Foodbot Factory: Objectives and features

Foodbot Factory is an evidence-based serious game which was created by a team of experts in nutrition sciences, dietetics, game development/computer science, and educational pedagogy and technology at Ontario Tech University. Foodbot Factory was designed to teach children ages 8-10 years of age (grades 4 and 5) about healthy eating and it is aligned with the CFG and the Ontario nutrition education school curriculum (Brown et al., 2020). It was released in the Google Play Store in June 2020. Foodbot Factory is grounded in self-determination theory and contains gamification and behavioural change techniques; thus it has the potential to be a novel serious game to facilitate learning about the CFG in elementary school settings. The Foodbot Factory serious game contains two main characters, scientists named Robbie & Rebecca, who have created Foodbots that help children make healthy eating decisions. With the guidance of the Foodbots and scientists, the user is led on a fun nutrition adventure where they learn about healthy eating choices (Brown et al., 2020). Foodbot Factory contains five learning modules related to four CFG food groupings of vegetables and fruits, whole grain foods, protein foods, and drinks; with protein foods being split into animal protein foods and plant-based protein foods learning modules. Each learning module has integrated learning objectives and gamification features and behaviour change techniques including gameplay and quizzes. Foodbot Factory also contains a Food Log so that users can access information about food and beverages encountered in the app (Brown et al., 2020). Foodbot Factory has undergone extensive testing with children as part of the development and evaluation process, as described by the Obesity Behaviour Research Trials (ORBIT) model. However, Foodbot Factory has not been evaluated in a more representative group of children or tested against a control group.

4.0 Objectives

4.1 Overview of Rationale

While nutrition knowledge provides the foundation for long-term nutrition behaviours and attitudes, further research needs to be conducted on the effectiveness of serious games on improving long-term nutrition knowledge in children within the school environment, specifically supporting the learning and retention of the CFG. There is also limited research on the effect of serious games on the knowledge and consumption of important high-quality foods such as whole grains, animal and plant-based protein foods, and water. While awareness and education on nutrition has increased in elementary schools in Canada, current learning in schools face problems around student motivation and engagement, and traditional schooling is perceived as ineffective and boring to many students, and serious games are a new and engaging way to enhance motivation and to learn about nutrition (Dicheva, 2015). To address these gaps, Foodbot Factory, the first novel serious games based on the CFG, presents healthy eating messages and covers a wide range of foods from the food groupings of the 2019 CFG. Despite the development and implementation of Foodbot Factory, there is no empirical evaluation conducted to determine whether Foodbot Factory increases overall nutrition knowledge in children.

4.2 Objective and Hypothesis

The primary objective of this study was to evaluate the effectiveness of the Foodbot Factory serious game on overall nutrition knowledge (composite outcome), as measured by the Food and Nutrition Attitudes & Knowledge questionnaire, in children aged 8-10 years of age, compared to the control group (Brown & Froome, 2020). The secondary objective was to assess if Foodbot Factory increases nutrition knowledge scores for each of the four main Foodbot Factory modules: Drinks, Whole Grain Foods, Vegetables & Fruits, and Protein Foods, compared to the control group. Additionally, a detailed examination of the learning; changes in baseline and end-of-study knowledge in module, which occurred in response to using the Foodbot Factory mobile serious game was conducted. It was hypothesized that the Foodbot Factory serious game would increase overall nutrition knowledge, and knowledge related to each of the four modules, compared to a control group.

CHAPTER 3.0:

THE EFFECTIVENESS OF THE FOODBOT FACTORY MOBILE SERIOUS GAME ON INCREASING NUTRITION KNOWLEDGE IN CHILDREN

Student Contributions: This study was conceived by me and my supervisor Dr. JoAnne Arcand. This study was designed by myself, Sheila Rhodes, Ann LeSage, Rob Savaglio and my supervisor Dr. JoAnne Arcand. The study intervention was refined by Jacqueline Marie Brown, Janette Hughes and Bill Kapralos. Carly Townson assisted with data collection. I analyzed the data and conducted the statistical analysis, with the support by Beatriz Franco-Arellano. My supervisor Dr. JoAnne Arcand oversaw all the aspects of the research.

Awards:

I won the 2020 George Beaton Award from the Canadian Nutrition Society, an award given for the best student work in the field of public health nutrition. This research was presented as a poster presentation at the Canadian Nutrition Society annual meeting. At this conference, I was selected to participate in the poster competition and won 2nd place out of 8 finalists.

Manuscripts:

Froome, H.M., Townson, C., Rhodes, S., Franco-Arellano, B., LeSage, A., Savaglio, R., Brown, J.M., Hughes, J., Kapralos, B., Arcand, J.(2020). The Foodbot Factory mobile application improves nutrition knowledge in children: Results of a randomized controlled trial. *Nutrients*. 12 (11).

Published Abstracts:

Froome, H.M., Townson, C., Rhodes, S., LeSage, A., Savaglio, R., Brown, J., Arcand, J. The Foodbot Factory mobile application improves nutrition knowledge in children: Results of a randomized controlled trial. Canadian Nutrition Society, [Virtual conference due to COVID-19]. May 2020. App Physio Nutr Metab. 2020: 45(4): S19

3.1 Abstract

The interactive and engaging nature of serious games (i.e., video games designed for educational purposes) enables deeper learning and facilitates behaviour change; however, most do not specifically support the dissemination of national dietary guidelines, and there are limited data on their impact on child nutrition knowledge. The Foodbot Factory serious game mobile application was developed to support school children in learning about Canada's Food Guide; however, its impacts on nutrition knowledge have not been evaluated. The objective of this study was to determine if Foodbot Factory effectively improves children's knowledge of Canada's Food Guide, compared to a control group (control app). This study was a single-blinded, parallel, randomized controlled pilot study conducted among children ages 8–10 years attending Ontario Tech University day camps. Compared to the control group ($n = 34$), children who used Foodbot Factory ($n = 39$) had significant increases in overall nutrition knowledge (10.3 ± 2.9 to 13.5 ± 3.8 versus 10.2 ± 3.1 to 10.4 ± 3.2, $p < 0.001$), and in Vegetables and Fruits ($p < 0.001$), Protein Foods ($p < 0.001$), and Whole Grain Foods ($p = 0.040$) sub-scores. No significant difference in knowledge was observed in the Drinks sub-score. Foodbot Factory has the potential to be an effective educational tool to support children in learning about nutrition.

3.2 Introduction

High nutritional quality diets are fundamental to optimal child physical growth and cognitive development (Health Canada, 2011; Tandon, 2016). Diets of lower nutritional quality are associated with lower cognitive and academic achievement, and a higher risk of developing long-term health issues such as type 2 diabetes, hypertension, and heart disease (Hurley, 2016; Reilly & Kelly, 2011). Moreover, the prevalence of overweight and obesity has risen among Canadian children and adolescents (Rao, 2016), which itself is associated with lower academic performance, feelings of social isolation, anxiety and depression, and low self-esteem and body image issues (Devaux, 2019; Nieman, 2012; WHO, 2017). Many Canadian children consume excess sodium and sugar from packaged foods and beverages and insufficient amounts of beneficial foods and nutrients including protein, whole grain foods and vegetables (Tugault-Lafleur & Black, 2019), which are dietary habits that may carry over from childhood to adulthood (Craigie et al., 2011). Subsequently, health promotion interventions to support the acquisition of nutrition knowledge, to improve nutrition literacy, and develop food skills during childhood are warranted in order to prevent negative health outcomes associated with poor quality diets. Nutrition knowledge and skills may be further enhanced by school-based nutrition policies and curriculum-based nutrition education (Critch, 2020), which are strategies employed in most jurisdictions within Canada; however, few studies have captured the impacts of policies or education (Korzun, 2014).

The use of gameplay through serious games to educate about nutrition is an emerging area in the nutrition education literature. Recent studies have shown that engaging apps, and the use of gamification and behavioural change techniques may increase intake of vegetables and fruits and increase engagement in food-related conversations in children (Brown et al., 2019; Champion, 2019; Holzmann, Schäfer, et al., 2019; Schoeppe, 2016; Skouw, 2020). In particular, serious games (i.e., video games designed for educational purposes) (Shute, 2009) have been shown to encourage participation and motivation in learning activities, which can promote higher academic achievement among elementary school children (Karyotaki, 2016). However, there are few evidence-based serious games that exist to support nutrition education for children and none known to support health promotion efforts in disseminating dietary guidelines (Girard et al., 2013; Hainey, 2016). In 2019, Health Canada published a new Canada's Food Guide (CFG), which was disseminated in an online-first format, with the majority of the CFG content published on a dedicated CFG website as opposed to traditional paper-based leaflets (Brown et al., 2020; Health Canada, 2019a). While this approach has the potential to facilitate access to nutrition information, the CFG website is didactic in nature and lacks engaging and motivating features, such as gamification and behaviour change techniques (i.e., avatars, games, quizzes, and rewards), known to enable deeper learning among children (Dicheva, 2015).

To address these gaps, the Foodbot Factory mobile application was developed by a team of experts in nutrition sciences, dietetics, game development/computer science, and educational pedagogy and technology at Ontario Tech University in Oshawa, Canada (Brown et al., 2020). Guided by the development and testing phases in the ORBIT model, Foodbot Factory is an evidence-based serious game that aims to engage children ages 8–10 years in learning about healthy eating and the new CFG. Foodbot Factory has been available as a free app in the Google Play store since June 2020 (University, 2020). Foodbot Factory contains five learning modules related to four CFG food groupings: Drinks, Whole Grain Foods, Vegetables and Fruits, and Protein Foods; the latter is organized into two learning modules: Animal Protein Foods and Plant-based Protein Foods (Brown et al., 2020). Each learning module has integrated game elements and behaviour change techniques that are used to enhance engagement with the app content (i.e., games within a game, humorous dialogue, a food log, quizzes) (Brown et al., 2020). Foodbot Factory has shown positive results in facilitating learning as part of the iterative development process (Brown et al., 2020); however, no empirical evaluation has been conducted to determine whether it improves nutrition knowledge. Therefore, the objective of this pilot study was to assess whether Foodbot Factory increased overall nutrition knowledge, specifically on the CFG, in children compared to a control app. Secondary outcome measures included changes in nutrition knowledge in each of the four sub-scores of Vegetables and Fruits, Whole Grain Foods, Protein Foods, and Drinks. A detailed assessment of learning and changes in nutrition knowledge was also conducted when children used Foodbot Factory, which was collected to provide data to inform future iterations of the app. Changes in nutrition knowledge was assessed through the percent difference between baseline and end-of-study knowledge.

3.3 Study Design and Setting

This study was a single-blinded, parallel, randomized controlled pilot study conducted during July and August 2019 (Ontario Tech University Research Ethics Board File #15385). It was conducted in a single center, at the Ontario Tech University summer day camps, which consisted of Coding, Tech-based, and Minecraft camps.

3.4 Inclusion and Exclusion Criteria and Recruitment

Children were eligible to participate in this pilot study if they were 8–10 years old and were entering grades 4 or 5 in September 2019. Only children who could read and write English were included. Participants were recruited from Ontario Tech University day camps. An invitation to participate in the study was sent to the parents of children who were enrolled in the camps. Informed consent was provided by parents, and assent was provided by children prior to participation.

3.5 Study Interventions and Protocol

Children were randomized to play Foodbot Factory or a control app called "My Salad Shop Bar" (GameSticky, Information updated 2020) for 10–15 minutes each day over a five day period (Figure 1). A different Foodbot Factory module and control app level was planned for each day of the study, facilitated by trained study personnel (author of the study) who followed a standardized protocol. The protocol was developed in collaboration with teachers and designed to mimic a classroom setting. Children sat in desks when using Foodbot Factory. A research assistant and day camp counsellor supported children if they had questions or needed help. Children in each group used the serious games on Android tablets that were provided by study personnel.

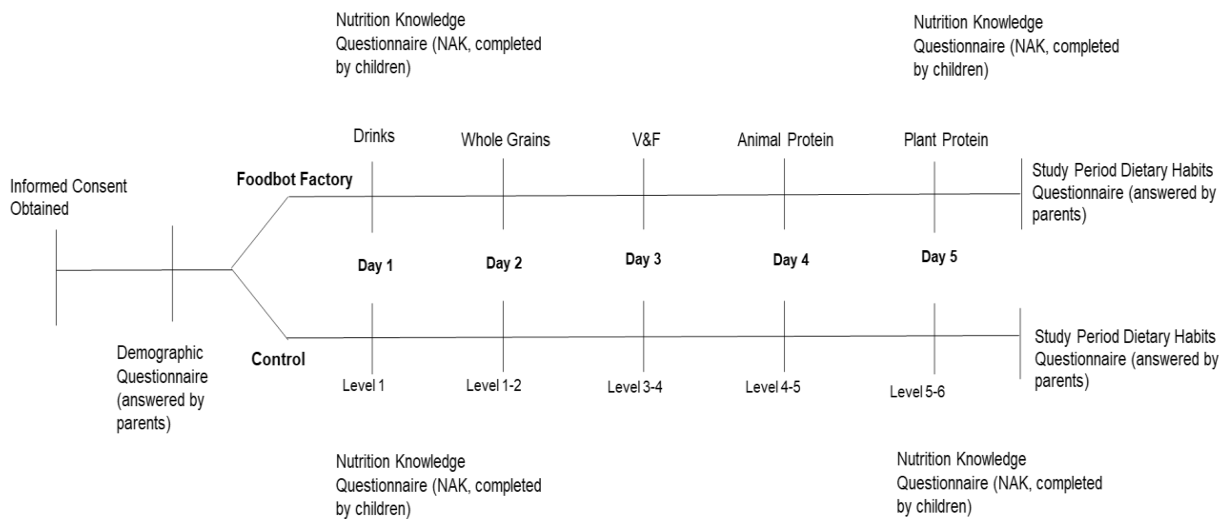


Figure 1. Study protocol for the week-long pilot randomized controlled trial

3.6 Randomization and Allocation

Participants were randomized into the intervention or control group at study baseline at a 1:1 allocation ratio. Randomization was stratified based on gender and grade entry in September 2019, as these were considered potential confounding variables of the primary endpoint. Randomization was conducted by the research coordinator using a computerized random letter sequence generator, with sequences in blocks of four letters. Due to the computerized randomization and allocation techniques, participants and day camp counselors were concealed allocation of children into the intervention and control group.

Intervention Group (Foodbot Factory): A different learning module of Foodbot Factory was played on each day of the study: Drinks on study Day 1; Whole Grain Foods on study Day 2; Vegetables and Fruits on study Day 3; Animal Protein Foods on study Day 4; and Plant-based Protein Foods on study Day 5 (Figure 2). Each module was played for 15 minutes. A voiceover was available to Foodbot Factory in order to enhance overall engagement and make the content more accessible for those who may have difficulty reading. The iterative development process for Foodbot Factory has been described elsewhere (Brown et al., 2020).

Figure 2. Screenshots of Foodbot Factory.

Control Group: A mobile application was chosen for the control group instead of comparing the intervention with the online CFG or traditional teaching methods, since this was a pilot study that intended to determine the feasibility and impacts of the Foodbot Factory app on changes knowledge among the target population for children, as intended for use in a larger study and in the classroom setting. The control group played the mobile application "My Salad Shop Bar" (GameSticky, Information updated 2020). This is a food-focused cooking game where the aim of the game was to challenge the player to prepare an order of healthy food (i.e., salads, fruit smoothies, whole grain breads, etc.) for customers. This app was chosen because it is a gamified mobile app that exposes the participants to a wide range of healthy foods. Each level takes up to five minutes to play; however, children were provided the opportunity to play the app for 15 minutes to ensure consistency with the intervention group.

For both the intervention and control groups, the protocol design took additional steps to minimize any factors that may introduce bias, confounding, co-intervention, and contamination. At the time the study was conducted, the Foodbot Factory app was not publicly available, so there was no risk for co-intervention. Participants in both study groups used the applications for the same duration of time in sessions that were led by a facilitator. Participants and parents were blinded to which app was the intervention and which was the control. To reduce the risk of contamination, the children in the control and intervention groups were separated into different rooms during the 15-30 minute study period. Possible confounding factors such as mobile device use at home and the use of nutrition apps were measured, and any noticeable changes in the children's knowledge and behaviour at home was also measured through a questionnaire sent to parents. A research assistant and a day camp counsellor was located within the intervention and control room at all times and was able to observe/monitor for participant adherence for the duration of the intervention delivery. As this study was a single-blinded RCT, research assistants were not blinded to group allocation. However any day camp counsellors who support study conduct had no knowledge of Foodbot Factory nor the study objectives, and was therefore were blinded to group allocation.

3.7 Primary and Secondary Outcomes

The primary outcome was change in overall nutrition knowledge, which was assessed at study baseline (Day 1) and at the end of the study period (Day 5). The secondary outcomes were change in nutrition knowledge for four sub-scores. These outcomes were measured with the validated Nutrition Attitudes and Knowledge Questionnaire (NAK), which was designed for and validated with school children 9-11 years of age (Appendix 2). The NAK questionnaire was designed to capture changes in nutrition knowledge from use of the Foodbot Factory. It took approximately 10–15 minutes to complete and was completed by children on a hardcopy paper rather than a tablet. The NAK is organized into four sub-scores that align with the CFG food groupings: Drinks, Whole Grain Foods, Vegetables and Fruits, and Protein Foods (Animal and Plant-based protein foods combined). The NAK questionnaire is comprised of 20 questions overall, with five questions allocated to each of the four sub-scores. The maximum score was 20 for overall knowledge. The maximum score was 5 for each of the sub-scores. All questions are equally weighted. Children circled the correct responses as questions are multiple choice and true/false. The sum score for each of the four sub-scores provides an overall nutrition knowledge score. NAK items were generated based on the 2019 CFG content and integrated into the four subcomponents in Foodbot Factory (Drinks, Whole Grain Foods, Vegetables and Fruits, and Protein Foods). The NAK underwent face and content validity with nutrition and education experts (n=7) and was assessed for construct validity with children ages 9-10 years (Appendix 3). The feedback provided by the experts resulted in minor wording medications, question conversion and the addition of two questions. The NAK also includes 5 questions related to attitudes, however this was not assessed as an outcome in the study.

Prior to randomization, parents completed a questionnaire that collected children's baseline demographic information and mobile device use/habits. The child's body mass index (BMI) was calculated based on parent-reported weight and height. At the completion of the study, parents completed an end-of-study questionnaire that captured any co-interventions or outside influences that may have affected the children's learning, and whether the children had any changes in their interest in food and nutrition at home (Figure 1).

3.8 Sample Size Calculation

The sample size calculation was based on data from a proof-of-concept study among children of a similar age who used the Foodbot Factory app. Considering an effect size of 3.2, a standard deviation of 3.2 and 80% power, 34 participants per group were required. The criterion for statistical significance was set at <0.05. We assumed a 20% attrition rate and recruited additional subjects to account for this consideration. This also accounted for any participants who were removed from the analysis.

3.9 Statistical Analyses

Continuous data are presented as means and standard deviations, and categorical data are presented as frequencies and percentages. Baseline characteristics between the two groups were analyzed using unpaired t-tests (continuous data) and the Chi-square test (categorical data). For continuous data, including the primary endpoint and secondary endpoints, two-way analysis of variance was measured between and within group differences in nutrition knowledge before and after the study period. A post hoc Tukey test was used to assess for the differences in time and treatment. A Chi-square test was conducted on the assessment of the correct answers in participants who used Foodbot Factory. A p-value of <0.05 was considered statistically significant. Data analyses were conducted in using the statistical software IBM SPSS Statistics 26. Intention-to-treat analysis was not conducted as there was a small sample of participants who dropped out or were excluded from the study.

3.10 Participants

A total of 496 of the children enrolled in the Ontario Tech University day camps were assessed for eligibility. Emails were then sent to the parents of 310 eligible children who met the study criteria, inviting their child to participate in the study. In total, 95 participants (34% recruitment rate) with consenting parents were enrolled and randomized into study groups. Overall, 22 participants were removed from the study: One participant from both the Foodbot Factory and control group dropped out, and ten participants from both the Foodbot Factory and control group were excluded from the analysis due to being absent from the camp for at least 2 days ($n = 15$), or being absent when the study outcomes were assessed ($n = 5$). The final data sample included 73 participants (Figure 3).

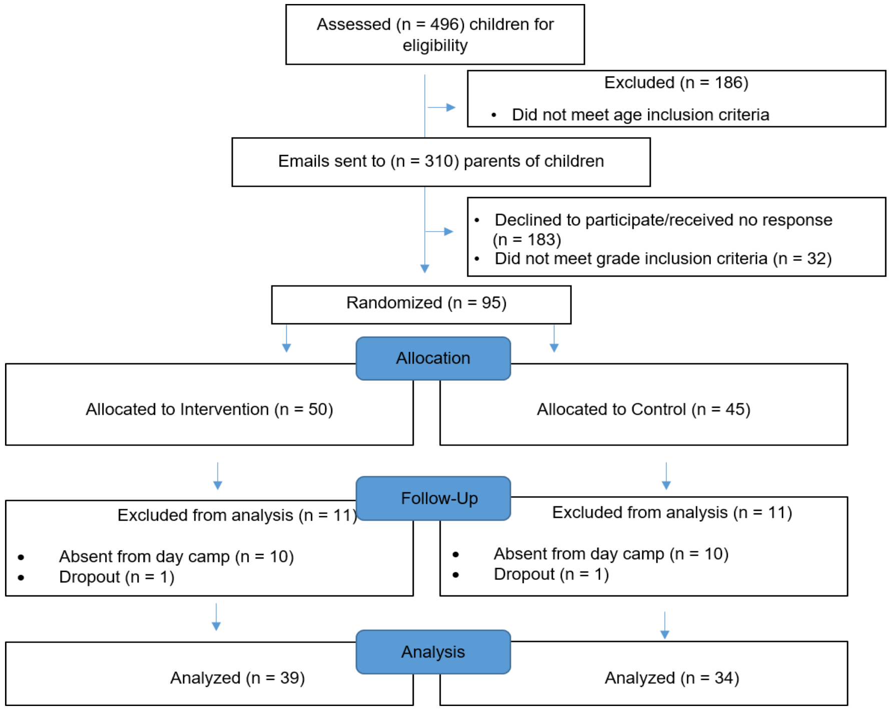


Figure 3. CONSORT Flow Diagram of subjects participating in the pilot randomized controlled trial.

3.11 Baseline Characteristics

Participants' baseline characteristics are described in Table 1. Overall, a higher proportion of participants (62%) were boys with an average age of 9.0 ± 0.8 years. The majority of participants in both the intervention and control group were of normal weight (59% vs 33%, p = 0.047) however the prevalence of obesity was higher in the control group (13% vs. 21%, p = 0.031). Significantly more participants in the control group (41% vs. 18%, p = 0.029) used a mobile device for learning at school. Most parents claimed that they often encouraged their children to follow a healthy diet *(*Foodbot Factory; 80%, Control; 79%, p = 0.994) and often talked about food and nutrition with their child (Foodbot Factory*;* 54%, Control; 74%, p = 0.084).

Table 1. Baseline Demographics and Mobile Device Use.

	Foodbot Factory (*n* = 39)	**Control (*n* = 34)**	***p*-Value [a]**
Age (years)	9.1 ± 0.7	8.9 ± 0.7	0.474
Grade (School)	4.4 ± 0.5	4.4 ± 0.5	0.643
Proportion in Grade 4	22 (55)	21 (62)	0.643
Boys	25 (63)	21 (62)	0.836
Male sex at birth	24 (60)	21 (62)	0.984
Body mass index (BMI, kg/m2)	18.1 ± 4.6	19.9 ± 6.7	0.661
BMI Percentile Categories			
Underweight: <5th percentile	4 (10)	1 (3)	0.045
Normal Weight: 5th to <85th percentile	23 (59)	13 (33)	0.047
Overweight: 85th to ≤95th percentile	5 (13)	5 (15)	0.062
Obese: >95th percentile	5 (13)	7 (21)	0.031
Child has access to a smartphone or tablet at home	37 (95)	32 (94)	0.890
Ways in which child accesses a smartphone or tablet			
They use a parent/guardian's device	13 (33)	14 (41)	0.489
They use a device at school	7 (18)	14 (41)	0.029
They use another adult's device	2 (5)	2 (6)	0.888
Child owns a device of their own	25 (64)	23 (67)	0.754
Not applicable	2 (5)	2 (6)	0.888
Frequency of use of nutrition mobile apps			
4 or more times a week	1 (3)	0 (0)	0.347
3 times a week	0 (0)	2 (6)	0.125
2 times a week	0 (0)	1 (3)	0.281
Less than once/week	5 (13)	12 (35)	0.023
None	17 (44)	7 (21)	0.037
Not applicable	16 (41)	12 (35)	0.615

Categorical data are presented as frequency (percentage). Continuous data are presented as mean SD. [a] *P*-values were calculated with Chi-square (categorical data) and unpaired *t*-tests (Continuous data).

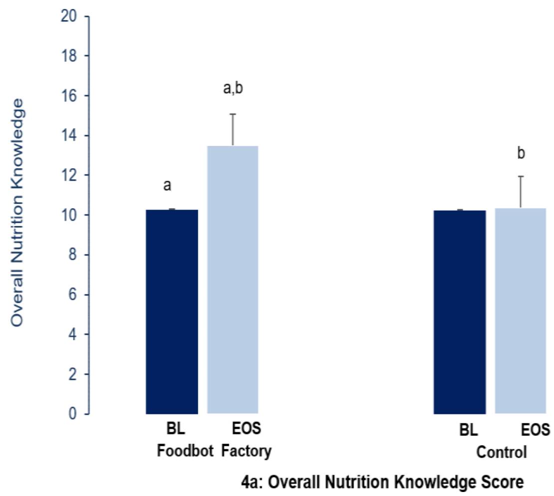
3.12 Changes in Overall Nutrition Knowledge and Sub-Scores of Knowledge

There were no baseline differences in overall nutrition knowledge or in any of the sub-scores between children randomized to Foodbot Factory and the control group. Baseline nutrition knowledge scores were relatively low in both the Foodbot Factory and control group. During the intervention period, a statistically significant increase in overall nutrition knowledge was observed in the Foodbot Factory group (10.3 ± 2.9 to 13.5 ± 3.8), compared to the control group (10.2 ± 3.1 to 10.4 ± 3.2, $p < 0.001$, Table 2, Figure 4a). Significant increases in nutrition knowledge were also observed in the Foodbot Factory group, compared to the control group, related to sub-scores of Vegetables and Fruits ($p < 0.001$), Protein Foods ($p < 0.001$), and Whole Grain Foods ($p = 0.040$). No significant increase in knowledge was observed between the two groups in the Drinks ($p = 0.206$); however, baseline knowledge of Drinks was already relatively high in both the Foodbot Factory (3.8 ± 1.0) and control (3.5 ± 1.2) groups (Table 2, Figure 4b–e).

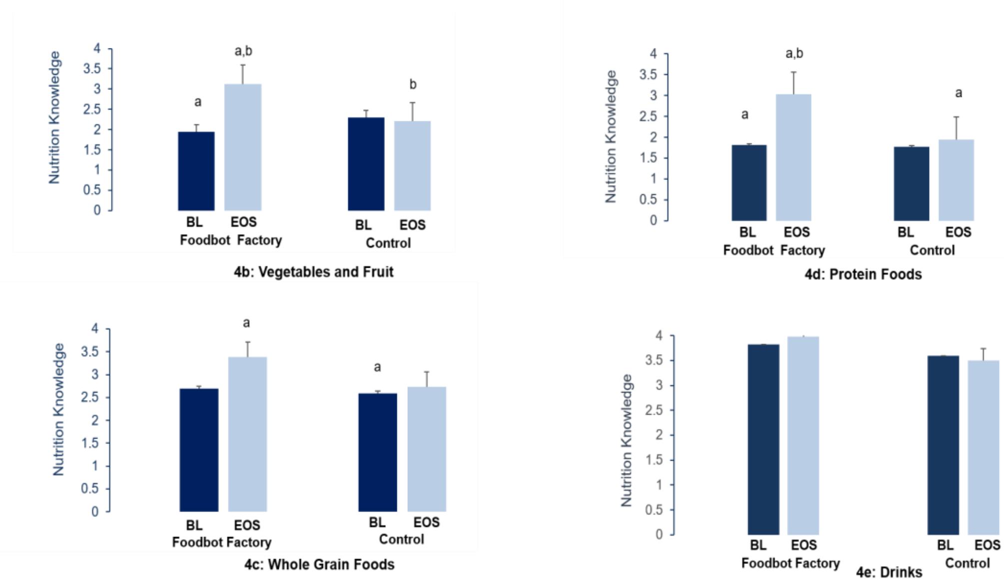
Table 2. Changes in overall nutrition knowledge and sub-scores of knowledge.

		Foodbot Factory (*n* = 39)		Control (*n* = 34)		
	Max Score	**BL**	**EOS**	**BL**	**EOS**	***p*-Value** [c]
Overall Nutrition Knowledge Score	20	10.3 ± 2.9 [a]	13.5 ± 3.8 [a,b]	10.2 ± 3.1	10.3 ± 3.2 [b]	<0.001
Whole Grain Foods Sub-score	5	2.6 ± 1.3	3.3 ± 1.4	2.5 ± 1.2	2.7 ± 1.1	0.040
Vegetables and Fruits Sub-score	5	1.9 ± 1.0 [a]	3.1 ± 1.5 [a,b]	2.2 ± 1.3	2.2 ± 1.1 [b]	<0.001
Protein Foods Sub-score	5	1.8 ± 1.0 [a]	3.0 ± 1.6 [a,b]	1.7 ± 1.0	1.9 ± 1.1 [b]	<0.001
Drinks Sub-score	5	3.8 ± 1.0	3.9 ± .74	3.5 ± 1.2	3.5 ± 1.1	0.206

BL = Baseline; EOS = End-of-Study. [a,b] indicates statistically significant within (a) and between ([b]) group differences. [c] As determined by the two-way analysis of variance.



(**a**)



(b)

Figure 4. Changes in overall nutritional knowledge and sub-scores of knowledge. (a) Presents data overall Nutrition Knowledge Score. **(b)** Presents data on the sub-scores for vegetables and fruit, whole grains, protein foods, and drinks. EOS: End-of-Study. BL: Baseline. [a,b] Between and within group differences lie.

3.13 Changes within the Foodbot Factory Application Questions

Further analyses were conducted to understand where exactly changes in nutrition knowledge occurred when children used Foodbot Factory. Table 3 shows a detailed assessment of correct answers among participants who used Foodbot Factory. For example, there was more than a 100% increase in correct responses to questions related to different types of fats and heart disease risk, types of fats present in animal protein foods, the proportion of a plate/meal that should be vegetables and fruit, and limiting canned vegetables and fruits that are high in sodium and/or sugar. While there were widespread improvements in nutrition knowledge after using Foodbot Factory, there were also individual items (questions) within each sub-group where little improvement was observed such as the nutrients found in dairy and soy milk, why drinking water is important, and what types of whole grain foods to choose most often. These individual items reflect more specific knowledge about a concept within a sub-group. These data can be used to inform future iterations of the app.

Table 3. Detailed assessment of correct answer among participants who used Foodbot Factory (*n* = 39).

	Baseline	End of Study	% Difference	*p*-Value [a]
Drinks				
Q1: Best choice to drink when thirsty	36 (92)	39 (100)	8%	0.077
Q2: Drink that should be enjoyed less often	37 (95)	37 (95)	0	1.000
Q3: Nutrient found in dairy & soy milk	13 (33)	10 (26)	−23%	0.411
Q4: Why drinking water is important	30 (77)	31 (80)	3%	0.784
Q5: Fruit juices are a sugary drink (T/F)	33 (85)	38 (97)	15%	0.048
Whole Grain Foods				
Q6: Grain foods to choose most often	30 (77)	32 (82)	7%	0.913
Q7: Examples of whole grains include	15 (39)	24 (62)	60%	0.039
Q8: Nutrients in whole grain bread	26 (67)	34 (87)	31%	0.016
Q9: Why fibre is important for health	13 (33)	18 (46)	38%	0.174
Q10: Nutritional content of refined grains	21 (54)	24 (62)	14%	0.576
Vegetables and Fruits (V&F)				
Q11: V&F are a good source of	19 (49)	22 (56)	16%	0.569
Q12: Consume V&F that are different	23 (59)	30 (77)	30%	0.110
Q13: Nutrient found in fruits vs. fruit juice	10 (26)	16 (41)	60%	0.347
Q14: Proportion of V&F on your plate/for a meal	12 (31)	27 (69)	125%	0.003
Q15: Limit canned V&F containing added sodium	12 (31)	27 (69)	125%	0.003
Protein Foods				
Q16: Fat of type and heart disease risk	10 (26)	26 (67)	160%	0.001
Q17: Protein food to choose most often	22 (56)	30 (77)	36%	0.035
Q18: Protein foods that are a source of fibre	17 (44)	18 (46)	6%	0.578
Q19: Nutrients in processed meats	15 (39)	24 (62)	60%	0.030
Q20: Animal protein is source if unsaturated fat (T/F)	7 (18)	20 (51)	185%	0.001

Data presented as frequency (percentage), Q = Question. T/F = True and False. [a] As determined by the Chi-square test. % difference represents difference between Baseline and End of study.

3.14 Changes in Nutrition Interests During the Study Period

Changes in nutrition-related interests that occurred during the study period were assessed, and any co-interventions that may have occurred, via a parent questionnaire at the end of the study. No significant differences between-groups were observed (Table 4). However, 62% of parents in the control group and 41% of parents in the Foodbot Factory group reported that their child mentioned food, diet, or nutrition “more than usual” in conversation.

Table 4. Changes in nutrition interests during the study period.

	Foodbot Factory (*n* = 39)	Control (*n* = 34)	*p*-Value [a]
Played food/nutrition apps or games at home			
Less than usual	2 (5)	1 (3)	0.639
No more than usual	28 (72)	23 (68)	0.700
More than usual	0 (0)	2 (6)	0.125
Don’t know	5 (13)	1 (3)	0.125
Not applicable	4 (10)	7 (21)	0.218
Mentioned food, diet, or nutrition in conversation			
Less than usual	0 (0)	0 (0)	
No more than usual	19 (49)	6 (18)	0.005
More than usual	16 (41)	21 (62)	0.077
Don’t know	0 (0)	0 (0)	
Not applicable	4 (10)	7 (21)	0.218
Showed interest in nutrition and healthy eating			
Less than usual	0 (0)	0 (0)	
No more than usual	18 (46)	12 (35)	0.347
More than usual	17 (44)	15 (44)	0.964
Don’t know	0 (0)	0 (0)	
Not applicable	4 (10)	7 (21)	0.218
Chose to eat healthier foods			
Less than usual	1 (3)	0 (0)	0.347
No more than usual	22 (56)	22 (65)	0.470
More than usual	11 (28)	5 (15)	0.164
Don’t know	1 (3)	0 (0)	0.347
Not applicable	4 (10)	7 (21)	0.218
Encouraged parent to buy healthy foods			
Less than usual	0 (0)	1 (3)	0.281
No more than usual	29 (74)	20 (59)	0.159
Less than usual	4 (10)	6 (18)	0.360
More than usual	2 (5)	0 (0)	0.181
Don’t know	2 (5)	1 (3)	0.639
Not applicable	4 (10)	7 (21)	0.218
Frequency study discussed between child and parent			
Every day	5 (13)	3 (9)	0.586
More than twice the past week	10 (26)	8 (24)	0.835
Once or twice this past week	18 (46)	13 (38)	0.495
Not at all this past week	2 (5)	3 (9)	0.533
Not applicable	4 (10)	7 (21)	0.218

Data presented as frequency (percentage); EOS = End-Of-Study. [a] As determined by Chi-square.

3.15 Discussion

This study has shown that Foodbot Factory, a novel evidence-based serious game mobile application designed to teach children about CFG, has the potential to be an effective learning tool that can result in long-term knowledge and nutrition outcomes in school-aged children. The need for novel digital tools for health promotion has been documented by several sources (Budd et al., 2020; Dzenowagis, 2018) and is clearly substantiated in light of the immediate transition to digital learning during the COVID-19 pandemic (Budd et al., 2020; The Lancet Digital Health, 2020). The children who used Foodbot Factory over a five-day period for an average of 15 minutes of nutrition education per day had significantly greater overall nutrition knowledge and sub-scores of nutrition knowledge (Vegetables and Fruits, Protein Foods, and Whole Grain Foods), compared to children who used the control application. At the end of the study period, participants received, in total, 75 minutes of nutrition education.

Improving food skills and nutrition knowledge in children are among several approaches to enable healthy eating behaviours during childhood and beyond (Craigie et al., 2011; Haines et al., 2019; Health Canada, 2019g). Nutrition knowledge and food skills enable individuals (youth and adults) to navigate complex food environments through evaluating and interpreting nutrition information to make healthy eating choices (Health Canada, 2019g). Nutrition education aims to encourage student confidence in their abilities to make healthy eating decisions, build skills to enhance their dietary behaviours, and understand factors, such as social media, that affect their food choices (Critch, 2020; Ontario Curriculum, 2019). Despite the inclusion of nutrition as part of the Canadian school curriculum (Ontario Curriculum, 2019), an understanding of children's use of nutrition information to assess food environments and make food decisions among children is minimal, and there is limited literature on what exactly Canadian children know about nutrition. Improving nutrition knowledge is a crucial public health priority and well-designed evidence-based digital interventions, especially those that involve gameplay via serious games, are an increasingly common and a highly effective method to engage children in learning, making education fun and enjoyable.

Research on serious games in health promotion is an emerging field, with studies demonstrating their impact on nutrition knowledge and behaviours (Champion, 2019; Rosi et al., 2015; Thompson et al., 2015). Many of the studies assessed reported positive impacts on nutrition knowledge, and health behaviour habits such as fruit and vegetable consumption, and/or intake of processed snacks (Baranowski et al., 2019; Holzmann, Schäfer, et al., 2019; Nollen et al., 2014; Smith, 2014). These studies align with findings conducted by systematic reviews (Champion, 2019; Chow, 2019; Schoeppe, 2016; Villinger, 2019), which have demonstrated that digital tools were efficacious in increasing nutritional knowledge, consumption of fruits and vegetables, nutrients, and decreasing consumption of sugary drinks. Whether the latter were multi-component or stand-alone interventions, all digital tools contained at least one form of gamification or behaviour change elements such as rewards, interactive elements and skill-based games to motivate and establish healthy eating behaviours (Champion, 2019; Chow, 2019; Nollen et al., 2014; Smith, 2014). In Canada, research on the impact of serious games on nutrition knowledge in children within the school environment is limited. Of 155 studies on serious games conducted through a systematic review, only 22 of these studies included digital and eHealth school-based interventions that assessed consumption of fruits and vegetables (n = 9), and consumption of sugar-sweetened beverages or snacks (n = 4) (Champion, 2019). After using Foodbot Factory, baseline knowledge increased from 10.3/20 (51%), and to 13.5/20 (68%). This is an overall increase of 3.2 points reflects a clinically meaningful increase in children's nutrition knowledge from 51% to 68%. It should be noted that there is still room for improvement in children's nutrition knowledge, even after using Foodbot Factory. Importantly, Foodbot Factory in this study was a single intervention. Once implemented into an elementary school environment, Foodbot Factory will be played alongside teachers who will use lesson plans and assignments to encourage deeper learning of the material presented in the game.

Currently, Foodbot Factory is the first novel, comprehensive serious game, based on the CFG, which has potential for improving nutrition knowledge amongst school-aged children in an engaging and intrinsically motivating way. Guided by the ORBIT model, this pilot test falls under *Phase II: Preliminary efficacy testing,* to show the feasibility and capacity of the intervention to product change in the outcome (Czajkowski et al., 2015). Therefore, a pilot study was the most appropriate method to examine Foodbot Factory during this stage of the evaluation process. As a serious game, Foodbot Factory incorporates various gamification elements and behavioural change techniques including feedback and monitoring, social support, shaping knowledge, natural consequences, reward, and threat, quizzes and sub-games requiring a user to catch food and sort food (Brown et al., 2020). These features are known to promote motivational learning, improve knowledge and healthy eating behaviour change in children, and promote engagement, which can increase educational achievement, and is likely responsible for the positive findings observed in the present study (Chow, 2019; DiFilippo, Huang, Andrade, & Chapman-Novakofski, 2015; Shute, 2009; The Lancet Digital Health, 2020). The success of well-designed serious games is supported by self-determination theory, in which intrinsic motivation (engagement due to interest) is separated from extrinsic motivation (based on rewards, avoiding punishments, etc.) (Chow, 2019; Ryan et al., 2006; Uysal & Yildirim, 2016). Serious games also address psychological needs to support motivation and well-being, such as promoting autonomy, competence, and relatedness (Ryan et al., 2006; Uysal & Yildirim, 2016). Considering the existing literature and positive findings observed in the present study, the data overall support the use of serious games in motivating children to learn about nutrition and healthy eating. Importantly, there is an opportunity to consider serious games as a health promotion tool, as opposed to didactic websites that currently exist for the CFG. Dissemination as a public health policy intervention, and the broader implementation of this tool used by educators, parents, and caregivers, can support the digital implementation of national dietary guidelines and addresses the lack of research the impact of digital tools has on improving nutrition knowledge.

The importance of technology in education has been emphasized in light of school closures globally amid the COVID-19 pandemic, with children learning at home via online classrooms (Ministry of Ontario, 2020). The need for and use of technology make health-focused serious games and eHealth tools a highly strategic avenue to address health, nutrition, and physical education. Evidence-based serious games, such as Foodbot Factory, that are comprehensive in scope have the potential to effectively promote deep nutrition-related learning. Yet, how these tools are implemented in schools requires further research. Although Foodbot Factory was tested in schools during the iterative development processes, implementation science approaches to empirically and qualitatively evaluate the real-life adoption and use of Foodbot Factory (and similar types of digital tools) are warranted in these settings. Adopting innovative game-based approaches as nutrition education interventions (and informing future iterations of such tools including augmented, virtual, or mixed realities) hold the potential to effectively increase nutrition knowledge by educating children about healthy eating (Chow, 2019).

This study has some limitations that need to be raised. In particular, this study was not designed to capture changes in dietary behaviours or health; however, our detailed assessments in knowledge gained provide a basis for conducting future research on these outcomes. This study was also short in duration, and not conducted in a classroom setting with a teacher and accompanying lesson. However, this study protocol was developed to mimic the classroom setting with regards to facilitation, the technology used (tablets), and the length of time participants played both apps were kept consistent. Exposure to nutrition apps could have impacted the findings. In particular, we found that significantly more children in the Foodbot Factory group used mobile apps, compared to those in the control group (74% vs. 41% $p = 0.002$). We did not assess the type of nutrition apps used (i.e., food-themed games, trackers, recipe apps). Importantly, there was no difference in nutrition knowledge between the two study groups at baseline, nor any parent-reported co-interventions over the study period. Furthermore, the study sample may not be representative of the general population of Canadian children due to the small sample size and being conducted at a tech-based day camp. While we controlled for gender during randomization, the sample included 62% and 63% of boys in the intervention and control group, respectively. Further analysis with a longer duration and larger sample size needs to be conducted to fully evaluate the long-term effectiveness of Foodbot Factory on nutrition knowledge and outcomes in children. Additionally, whether the participants were aware and had learned about the 2019 CFG prior to the study was not assessed; however, baseline knowledge was similar between the intervention and control group. Lastly, parent demographics, socio-economic status and geographic location was not collected for this pilot study. As these factors may have an effect on children's dietary habits, collecting parental demographics, socio-economic status and geographic location will need to be considered in future larger-scale studies on Foodbot Factory. Collecting this information will address whether Foodbot Factory is generalizable to the broader Canadian population.

This protocol was developed in collaboration with teachers and reflected the classroom experience as much as possible. In fact, the results of this study may have underestimated the educational impact of Foodbot Factory in a classroom setting, as the app would be accompanied with teacher instruction and related activities and assignments. A major strength of this study is that it was the first known randomized study in Canada to evaluate the effectiveness of a digital engaging evidence-based serious game on improving nutrition knowledge and the new content of the 2019 CFG.

3.16 Conclusions

This study has shown that Foodbot Factory has the potential to be an effective digital tool to engage children in learning about nutrition, resulting in significant improvements in nutrition knowledge overall and across most sub-scores of nutrition knowledge. These data demonstrate the broader use of serious games to support the dissemination of healthy eating dietary guidance and in facilitating learning about healthy eating among children in elementary school and home environments. The need for novel digital tools in both global public health and health promotion interventions has been documented (Budd et al., 2020; Dzenowagis, 2018). Future research needs to include assessments of changes in long-term healthy behaviours and dietary intake in response to using digital applications to fully understand the effectiveness of this digital learning tool. Data generated in this study can support evidence on the development of future digital tools and the use of gamification and behavioural change techniques to positively influence children's nutrition education worldwide.

CHAPTER 4.0: DISCUSSION

4.1 Discussion of Findings and Future Directions

This thesis evaluated the extent to which Foodbot Factory, a novel evidence-based serious game, can increase nutrition knowledge in children, compared to a control app. Foodbot Factory was designed to be implemented into the elementary school curriculum to teach Canadian children about the CFG. The results of this research demonstrates that children who used Foodbot Factory over a five-day period for an average of 15 minutes per day, have a significantly greater overall increase in nutrition knowledge and sub-scores of nutrition knowledge (Vegetables and Fruits, Protein Foods, and Whole Grain Foods), compared to children who used the control application. These results suggest that Foodbot Factory is an effective digital tool to engage children in learning about the CFG.

The development, testing and evaluation of Foodbot Factory was conducted by an interdisciplinary research team and guided by the ORBIT model. The ORBIT model is a framework used to guide the development and evaluation of health behavioural interventions, adapted from the process used in new drug development (Czajkowski et al., 2015). The model involves four phases that contain pre-specified milestones, with a progressive process for forward movement, and return to earlier stages for intervention refinement and optimization (Czajkowski et al., 2015). The four stages of the ORBIT model include *Phase I: Design, Phase II: Preliminary Testing, Phase III: Efficacy testing and Phase IV: Effectiveness research*. For Foodbot Factory, *Phase I* included in the development (goals, content, features) and iterative testing (5 user testing sessions) of each Foodbot Factory module by a team of experts in nutrition sciences, dietetics, game development/computer science, and educational pedagogy and technology (Brown et al., 2020). At this time user-metrics of usability, engagement and learning were collected, which informed subsequent prototype iterations. Next, Foodbot Factory was tested as part of Phase II Preliminary testing, which includes two sub-phases: *Proof of concept (a) and Pilot (b).* The aim of the "proof-of-concept" testing phase *(Phase IIa),* is to understand if the intervention merits more rigorous evaluation such as the use of randomized study designs (Czajkowski et al., 2015). Following the development of Foodbot Factory, a single arm, pre-post proof-of-concept study was conducted in a grade 4 classroom (n=25) within an elementary school. Participants played Foodbot Factory for 20-30 minutes for two days (approximately 15 minutes per food group module) (data unpublished). This evaluation demonstrated that Foodbot Factory can significantly improve overall and sub-scores of nutrition knowledge related to Whole grain foods, Vegetables and Fruits and Protein foods (Brown & Froome, 2020). Thus, it was concluded that Foodbot Factory achieved the *Phase IIa* milestones based on its intended outcomes. The next stage for Foodbot Factory is *Phase IIb*, which includes pilot testing, and is the focus of this thesis (Czajkowski et al., 2015).

The goal of this current phase, *Phase IIb: Pilot Testing,* is to determine whether a clinically significant benefit on the behavioural risk factor can be achieved in a larger, more representative sample (Czajkowski et al., 2015). This phase usually involves randomized designs. In the case of Foodbot Factory, the outcome of relevance is an increase in nutrition knowledge. Conducting a pilot study in this point assess the feasibility of Foodbot Factory in enhancing nutrition knowledge in the population of interest. This will provide evidence for future research on a larger-scale RCT that will examine efficacy and effectiveness and increase the likelihood for success by exploring internal and external validity in more depth. This thesis research found that Foodbot Factory facilitated greater increases in overall and sub-scores of nutrition knowledge compared to children who used a control nutrition app. Importantly, the NAK questionnaire used in this thesis research underwent face, content and construct validity testing (Appendix 3, manuscript under review). Additionally, as Foodbot Factory on its own had a significant increase in the overall and sub-scores of nutrition knowledge, it is expected that once this serious game is integrated into a classroom setting with an accompanying lesson, there will be a clinically meaningful increase in nutrition knowledge.

Thus, it can be concluded that *Phase IIb: Pilot Testing* was successfully achieved. The next two phases of the ORBIT model are *Phase III: Efficacy Testing* or *Phase IV: Effectiveness Research*. Theoretically, Foodbot Factory would be evaluated in terms of whether the outcome and magnitude of change produced by the intervention is "clinically" meaningful in a classroom environment. Considering Phase III in the ORBIT model, future research with Foodbot Factory should assess longer-term nutrition knowledge and behavioural outcomes such as intake of Vegetables and Fruits, Whole Grains and Protein foods. This research could be conducted through a parallel RCT in an elementary school alongside teachers, which would be appropriate for the *Phase III: Efficacy Testing.* This is due to parallel RCTs generally answering questions about whether there are any statistical significant benefits and risks associated with the intervention (Hui, Zhukovsky, & Bruera, 2015). Additionally, a cluster RCT design could also be considered to be used throughout multiple elementary schools to represent an even larger sample of children across varying sociodemographic statuses. Cluster RCTs are better used to evaluate the effectiveness of an intervention (i.e., understanding the effects of an intervention in a real-world setting) as opposed to efficacy (i.e., how well intervention works under ideal circumstances) (Velengtas, Mohr, & Messner, 2012). These types of studies would provide novel evidence to support the broad use of Foodbot Factory as part of standard practice for teaching children about nutrition in elementary school classrooms.

The use of digital means for dissemination of health promotion material has highlighted the importance of Foodbot Factory, especially in response to COVID-19 that shifted learning online for many students globally. Foodbot Factory and other serious game-based digital technologies can support the Canadian population through virtual environments (Budd et al., 2020). A gap in evidence-based digital resources was highlighted in an environmental scan of apps (n=142 food apps) available on the Canadian marketplace (Google Play Store, Apple App Store). Only few apps displayed healthy foods such as whole grains (4%), plant based proteins (10%) or fish (14%) and only a small proportion of apps included healthy eating messages (3%) (Brown et al., 2019). To our knowledge, there is no current or future provincial or federal government plan to support the dissemination of national healthy eating information, in Canada or internationally, through the use of mobile applications and serious games. Other than Foodbot Factory, no known serious game has been developed to facilitate learning about the CFG among children. The availability of evidence-based educational digital tools is critical with the transition to digital learning in elementary schools with provincial and school district authorities promoting online and blended learning as the next step toward integrating effective technology into elementary schools (Bennett, 2016). Provincially, the Ontario Minister of Education announced a $15 million purchase for thousands of classroom computers to ensure students return to school with the tools they need to succeed (Ministry of Ontario, 2020). This thesis research showed that Foodbot Factory has the potential to support the implementation of these educational policies for technology integration within the classroom using a fun and engaging learning environment which can enhance the user's engagement and motivation learning about nutrition.

This thesis sought to add to the literature on the effectiveness of serious games on nutrition knowledge in Canadian children, specifically on the CFG. Nutrition knowledge is an important factor for affecting nutrition behaviour acquired in childhood, as children with adequate nutrition knowledge can differentiate and select foods with a high nutrition value (Demirozu, 2012). As dietary patterns and habits begin in childhood, nutritional knowledge acquired at this stage can support individuals in navigating the food environment and promote long-term healthy eating choices and dietary habits in childhood and throughout the lifespan (Health Canada, 2019d). Nutrition education is included into the school curriculum of all Canadian provinces (Ontario Curriculum, 2019; PHE Canada). Little is known about whether Canadian children are understanding and retaining the nutrition curriculum in elementary schools and can apply the learned nutrition knowledge in real-life settings; however, a longitudinal study on a Nutrition Report Card on food environments for Canadian children has highlighted these research areas as priorities for future research (Ferdinands, 2020). The World Health Organization has emphasized the importance and implementation of appropriate, affordable, and sustainable digital health solutions as key components of a national strategy to promote health and wellbeing (World Health Organization, 2020). Serious-game-based nutrition interventions are one way to improve nutrition education and food skills in children. This thesis research has shown that Foodbot Factory, when implemented into a mock school environment, significantly increased nutrition knowledge in children, specifically on the CFG. Currently, Foodbot Factory is the first novel, serious game based on the CFG, which has the potential for improving nutrition knowledge amongst school-aged children and can be considered for adoption among teachers in classrooms or parents and caregivers.

While this thesis research was not designed to capture changes in short or long-term knowledge and dietary behaviours or health, the data on knowledge gained by study participants provides a basis for conducting future research on these outcomes. Future research should focus on measuring longer-term impacts of Foodbot Factory on nutrition knowledge attitudes and outcomes in Canadian children. However, valid and reliable instruments developed to measure nutrition knowledge is another important consideration in future research, as highlighted in a recent review by (Newton, 2019). While the development of questionnaires to capture nutrition knowledge in children has occurred globally, to our understanding, the NAK questionnaire is the first known tool developed to capture nutrition knowledge in Canadian children related to the 2019 CFG. Newton et al found that of the knowledge tools used in the scientific literature (n=67), there was a lack of reporting in terms the description of knowledge tools and their psychometric properties, which makes the selection of appropriate instruments extremely difficult (Newton, 2019). While Foodbot Factory has been shown to be effective at increasing nutrition knowledge, more knowledge assessment tools, such as nutrition questionnaires like the NAK, are needed in Canada to capture what children know about nutrition and whether they are understanding and applying what is being taught in elementary schools. This would also provide researchers with valid tools to measure the impacts of interventions.

4.2 Conclusion

This research showed that Foodbot Factory significantly increases overall and sub-scores of nutrition knowledge, compared to a control app. Results from this study suggest that Foodbot Factory has the potential to be an effective serious game to engage children in learning about nutrition and could support elementary teachers, parents and caregivers in facilitating learning about healthy eating for children. This data demonstrates the broader use of serious games to support the dissemination of healthy eating dietary guidance and in facilitating learning about healthy eating among children in elementary school and home environments. Serious games are an increasingly popular and effective method to teach children about nutrition. Amid the current COVID-19 pandemic and changing trends in education and health promotion there is a need for digital tools to support public health policies and health promotion interventions (Budd et al., 2020; Dzenowagis, 2018; Global Conference on Primary Health Care, 2018). The World Health Organization has emphasized the importance and the implementation of appropriate, affordable, and sustainable digital health solutions is a key component of a national strategy to promote health and wellbeing (World Health Organization, 2020). Data generated in this study can be used to support the development and implementation of future digital tools and the use of gamification and behavioural change techniques to positively influence children's nutrition education and knowledge within the food environment.

Appendices

Appendix 1. Applications that Examine Serious Games and Children on Nutrition Knowledge and Behaviours

Study (Country)	Study Design	Participants	Intervention Duration & Intensity	Characteristics of the Intervention	Nutrition-related Outcomes & Measurements	Results
Holzmann (2019), Germany	Pilot Study, Cluster RCT	n=36 among children and adolescents aged 12 and 13	15 min gameplay session for 3 consecutive days **Fit, Food, Fun (FFF):** Digital gameplay group. Impart nutrition knowledge in an entertaining format. **Control:** Teaching group. Taught on blackboards with quizzes and open-ended questions.	Gamification elements such as mini-games, quizzes, bonus points, unlock levels throughout Journey through Europe with each country focusing on country-specific food items.	Assessed pre and post-intervention (3 days). Nutrition Knowledge, dietary behaviour and non-nutrition outcomes were assessed. Nutrition knowledge assessed by questionnaire. Dietary behaviour assessed by 45 item food frequency questionnaire	Improvement in overall nutrition knowledge scores in the intervention group (+0.31 to +0.42, p = 0.001) and control group (+0.29 to +0.45, p<0.0001). Knowledge in whole grains, sugar and salt, fats and oils, lifestyle, water and beverages, and FV increased in the intervention group (+0.25 to +0.33, p=0.02) and control group (+0.24 to +0.39, p<0.0001).
Bell et al (2018), United States	Quasi-experimental pilot RCT	n=180 3rd, 4th, and 5th grade students n=2 public elementary schools. Total 12 classrooms (6 per school).	3-week program. 3 virtual sprouts gaming sessions, 3 school lessons and 3 in-home activities.1 hour game play. **Virtual sprouts intervention:** Interactive multiplatform mobile gardening game **Control:** Did not participate in any gameplay	Avatar, series of cooking and gardening activities. Narrative, touch-based technologies, Dotty: a ladybug and pedagogical agent whose job is to help the children learn and navigate the game. Nutrition and gardening focused curriculum	Pre and post intervention questionnaires used to assess psychosocial determinants of dietary behavior, knowledge and self-efficacy to eat FV Data collected on FV, whole grains, fibre, total sugar, added sugar, and energy from sugary beverages through the Block Kids Food Screener.	Improved self-efficacy to eat, cook, and garden FV in intervention compared with control (1.9% increase vs. 7.5% decrease in control; p = 0.01). Mean self-efficacy to eat fruits and vegetables score increased in intervention compared to control (1.6% increase vs. 10.3% decrease in control, p = 0.01).

Study (Country)	Study Design	Participants	Intervention Duration & Intensity	Characteristics of the Intervention	Nutrition-related Outcomes & Measurements	Results
Nystrom et al (2017), Sweden.	RCT	n=315 children aged 4.5 years	6-month health program. Wear an accelerometer for 24 h/d for 7 consecutive days for physical activity and sedentary behaviours **MINISTOP Intervention:** Centered on guidelines for healthy eating in school-aged children. 12 themes. New theme introduced bi-weekly. **Control:** Pamphlet on healthy eating and physical activity.	**12 themes:** Healthy foods, breakfast, healthy small meals, candy and sweets, FV, drinks, eating between meals, fast food, sleep, foods outside the home. Foods on special occasions, physical activity and sedentary behavior. Topics had information, advice and evidence-based strategies to change unhealthy behaviour. Social connection among parents.	Dietary and PA variables assessed 2 weeks after visit. Follow-up measured at 6 months. Primary outcome: Body Fat (Fat Mass index; FMI) and Fat-free mass index calculated as fat or fat-free mass (kilograms) divided by height (meters) squared. Weight, height, air-displacement plethysmography (body composition). Secondary outcomes: Intake of FV, candy, and SSB. Assessed with 'Tool for Energy Balance in Children and photographs of all food and drinks for 4 days (assessed by nutritionist)	Intervention group decreased intake of sweetened beverages compared to control (-12 ± 85 mL/d versus +8 ± 83 mL/d, p =0.049), increased fruit intake compared to control (+2.9 ± 78.9 g/d versus -12.1 ± 87.9 g/d, p=0.262) 7 component-composite score: combination of dietary and PA variables, and FMI. Includes intake of FV, candy, SSB and sedentary time. At follow-up, intervention group improved composite score from baseline compared with the control group (+0.36 ± 1.47 units versus -0.06 ±1.33 units, p=0.021)
Gabrielli et al (2017), Italy.	Pre/post pilot study.	n=6 parents with overweight (BMI 85^{th}-94^{th} percentile) children (7-12 years)	6-week intervention. Intensity not described. **TreC-Lifestyle:** Mobile app on parent's phone with nutrition education features to support behaviour change. Used by parents and children. Aims to raise parent's awareness of children's eating behaviours and lifestyle.	Monitoring and feedback. Human and virtual coaching. Colour bars to display balance of nutrients in children's meals. Shopping list feature. Notifications reporting guidelines. Child wore activity tracker and checked with achievement of the activity goal of 10k steps per day on the app.	Parent usability of app assessed at 3 and 6 weeks through System Usability Scale Questionnaire. Post-intervention interviews. Another follow-up phase occurred during summer holidays (not clear when) Outcome: Parents adherence and Knowledge of the guidelines provided by the Mediterranean diet and app usability. Self-reporting. Children's daily food intake reporting done by parents on app dashboard. Qualitative evaluation on usability and knowledge of the Mediterranean diet (interviews)	Parent's knowledge of Mediterranean diet improved post intervention (+12.5 to +12.7 out of 15 points). More than 80% correct responses.
Sharma et al (2015). United States.	Quasi-experimental RCT	n=44 children in grades 4 and 5. n=3 intervention schools.	90 min/wk for 6 weeks. Average 4.6 hours during the 6 weeks (51% of recommended dosage). **Lava Mountain Intervention:** Web-based computer game that helps apply five core concepts: food is fuel, food and PA are related, healthy foods and	Avatars, mazes, interactive activities. Avatars experience low performance in completing quests upon choosing foods/beverage and recipes containing added sugars and fats. Challenging through progress.	Assessment completed at pre and post intervention. Dietary behaviours, physical activity behaviours and psychosocial factors. Dietary intake measured using 2 random 24 hour-recalls. Self-report surveys measured diet, PA and psychosocial factors. Attitude	Intervention group reported decreased sugar consumption compared to control group (+55.35 ± 13.47 g/1,000 cals to +50.45 ± 18.93 g/1,000 cals versus +55.33 ± 16.94 to +60.94 ± 15.97 g/1,000 cals, p = 0.021). Higher nutrition/physical activity attitude scale (+6.04 ± 1.35 score to +6.89 ± 1.57

Study (Country)	Study Design	Participants	Intervention Duration & Intensity	Characteristics of the Intervention	Nutrition-related Outcomes & Measurements	Results
			beverages are optimal for health, healthy diet is moderation, physical activity helps maintain optimal health **Comparison:** Usual programs. Received no computer game.		assessed with Computer-Assisted Learning Scale (10 items)	score versus +6.47 ± 1.12 score to +6.44 ± 1.16 score, p = 0.041).
Thompson et al (2015). United States	4-group randomized design	n=400 children Age: 9-11 years and their parents	5 Weeks of 10 sessions total. 25 min per session. **4 groups: Control, action, coping, both** **Action**: Set FV goal, create action plan, specify how goal was met. **Coping:** Set goal to eat FV, create coping plan to identify barriers. **Both:** Eat FV, create both action and coping plans. Creation of action plan, then follow barrier and solution. **Control:** played game but only set goal to eat FV.	Self-representation of avatar, Narrative context, Feedback, Rewards, Different levels of play, Challenges, Progress. 10-episode game that encouraged consumption of at least five servings of FV every day.	Data collected at 3 time points: baseline, immediate post-intervention, 3 months post-intervention 3 unannounced 24 hour recall over phone. FV intake assessed by 24-hour recalls at baseline, immediately post intervention and 3 months post-intervention.10 sessions (25 minutes each) for 5 weeks.	Immediately after intervention increases in FV were observed throughout the follow up periods in the action group (+1.64 ± 0.04 servings to +2.37 ± 0.04 servings to +2.32 ± 0.04 servings, p<0.0001) and coping group (+1.83 ± 0.04 servings to +2.31 ± 0.04 servings to +2.11 ± 0.05 servings, p<0.001).
Rosi et al (2015). Italy.	Single-group education intervention	n=3 fourth grade classes. n=79 aged 8 to 10 years of age.	Duration of 3 months. Classroom activities daily for 3 months. **5 a day game:** Computer technology edutainment platform used for encouraging FV consumption. And to teach and improve healthy eating and lifestyle habits through games,	Menu composer game and the jump mania game, a cookbook. 5 day manual. JummpyFive – a multimedia character as designed and implemented to help children in the learning process.	Encouraging children towards higher consumption of FV. Children completed 2-day food diaries pre-test of FV and juices. At end of the 5 a day activity, children filled in 3-day food diaries.	Total consumption of FV increased (+421.8 ± 320.2 g/day to +484.3 ± 337.2 g/day, p = 0.016). Total increase for vegetables alone increased (+152.7 ± 109.1 g/day to +186.4 ± 135.7 g/day, p = 0.001).
Johnson-Glenberg et al (2014). United States.	Feasibility study	n= 108 Dutch children, from 20 grade 6 and 7 classrooms	50 minutes per day for 2 consecutive days **Alien Health game:** Web-based nutritional game. Players learn nutrients in common food items and practice making food choices. **Control:** Web-based nutrition game with same performative food choices at interactive whiteboard but did not exercises.	Narrative. 5 nutrients (proteins, fats, carbohydrates, fiber and vitamins/minerals) are learned. Multiple levels. Feedback on quality of performed exercises. Both groups watched play on a whiteboard. All participants were exposed.	Nutritional knowledge assessed at pretest, immediate and 2-week follow-up. Nutrition and food choice test. Contained mixture of 31 forced choice and open-ended items along with a blank template of the MyPlate icon for students.	Nutrition knowledge scores in intervention group increased from +67.0 ± 11.23 to +73.50 ± 10.51 out of 100 immediately post-test with an effect size of 0.60. 2-week follow-up scores increased from pretest from +67.0 ± 11.23 to +77.40 ± 7.01. Nutrition knowledge scores in control group increased from +67.20 ± 11.12 to +78.05 ± 11.19 out of 100, with 0.97 effect size. 2-week follow-up scores were not maintained (+67.20 ± 11.12 to +75.40 ± 8.70 out of 100).

Study (Country)	Study Design	Participants	Intervention Duration & Intensity	Characteristics of the Intervention	Nutrition-related Outcomes & Measurements	Results
Nollen (2014). United States.	Pilot RCT	n=51 girls aged 9-14 years	12-week intervention. Three 4-week modules (FV: Week 1-4; SSB: Week 5-8; Screen-time: Week 9-12). **Intervention:** MyPal A626 handheld computer. Stand-alone app. Grounded in behaviour weight control principles **Control:** Manuals at weeks 1 (FV); 5 (SSB); and 9 (screen time). Relied on participants to initiate goal setting, planning and self-monitoring	Education and feedback, goal setting, morning general reminder, daily goal reminders, self-monitor progress, assessment of goal completion, FV diary, encouragement and problem solving, reward system, health education, nightly feedback and goal planning.	Follow-up measured at 4, 8 and 12 weeks. Intakes of FV and SSB and screen time. FV intake measured at baseline and week 2 using 2 item screener. Assesses servings of FV eaten on a typical day via a 15 item questionnaire.	Intervention group trends toward increased FV intake on 63% of days (+2.53 ± 1.45 daily servings to +3.35 ± 1.81 daily servings) (+0.88, p = 0.08) compared to control (p=0.79) and decreased sugar sweetened beverages (+1.20 ± 0.92 daily servings to 0.87 ± 0.93 daily servings) (-0.33, p = 0.09) compared to control (p=0.94). Increased FV consumption in intervention from +4.0 daily servings at baseline to +5.6 daily servings at Week 2 (p< 0.05).
Majumdar et al (2013). United States	Pre- and post-matched pair intervention and control design	n=590 students aged 11-13	2x week for one month. 9 sessions of 30 minutes. **Creature-101:** Computer game engine called open space to target a range of eating and PA behaviours such as increase. **Control**: Online game called Whyville once a week for a month. Engage users in learning about a broad range of topics.	Self-representation of avatar, Narrative context, Feedback, Rewards, Different levels of play, Challenges, Progress Educational content derived from nutrition science curriculum. Aims to reduce risk of obesity by physical activity and nutrition behaviours.	First and last session or pre and post-test survey. Energy balance related behaviours such as increase in FV intake, water intake, and physical activity, decreasing processed snacks intake, SSB intake, and recreational screen time. Assessed through self-reported 41-item online instrument that measured frequency and amount of behaviours at baseline and post-intervention.	Intervention group had decreased intake of SSB compared to control (+1.43 ± 0.87 once per day vs. +1.76 ± 0.9 once per day 7, p<0.007.). Intervention had increases of water intake compared to control (+3.16 ± 1.29, 5-6 times per week vs. +3.12 ± 1.34, 5-6 times per week, p=0.694), and increased FV intake compared to control (+3.00 ± 1.20 vs. +2.77 ± 1.29, 3-4 times a week, p=0.210).
Schneider et al (2012). United States.	Pre & post-test	n=97 elementary school students Four student cohorts participated.	52 min per session for 5 consecutive days. One cohort played for 4 days (school closure). **Fitter Critters:** Online videogame intended for use in children. Aims to facilitate behaviour change through knowledge of behaviour, Behaviour change skill development and self-control skill development.	17 questions for motivation, master game basics, and increase nutrition and activity knowledge. Player responsible for virtual pet. Food, cooking and sports games, work, sick days, decorations.	15 minute baseline questionnaire and post-game questionnaire. Aim to increase healthy eating, nutrition and activity knowledge and health behaviours. Nutrition knowledge measured with 14 item validated questionnaire. Self-efficacy assessed with valid 8 item PA self-efficacy scale. Attitudes measured with valid 14 item questionnaire of healthy eating	Increases in diet self efficacy scores from pregame to postgame (36.85 ± 6.51 to 38.50 ± 7.64, p=0.009). Positive diet attitudes scores from pregame to postgame (59.14 ± 6.08 to 62.22 ± 7.74, p<0.001). Diet knowledge scores from pregame to postgame (10.71 ± 1.97 to 11.04 ± 1.91, p=0.08).

Study (Country)	Study Design	Participants	Intervention Duration & Intensity	Characteristics of the Intervention	Nutrition-related Outcomes & Measurements	Results
Baranowski et al (2011). United States.	RCT	n=133 children aged 10-12 years, initially between 5th percentile and 95th percentile BMI.	Approx. 40 min per session. 9 total sessions. **Diab and Nano Intervention**: 9-level action-adventure video games on children's diet, physical activity, and adiposity. **Control:** Diet and PA knowledge based games on popular websites	Knowledge mini game, goal setting, problem solving, motivational messages (with reasons statement linking the selected behavior change), and a goal behavior menu.	Assessment at baseline, immediately after intervention and control, and at 2 month follow-up. Servings of FV, water, and minutes of moderate to vigorous PA (sedentary and light PA was also captured). 3 non-consecutive days of 24-hour dietary recalls. 5 consecutive days of PA using accelerometers. Assessment of non-nutrition outcomes. Participants for PA were only included in analysis if they provided at least 4 days of valid (at least 800 minutes) of accelerometer data.	Increased FV in intervention compared to control in the 3 follow-up sessions ($p = 0.018$ between groups). Intervention: Baseline: +1.88 ± 0.13 servings per day Immediately after intervention: +1.85 ± 0.13 servings per day 2 months follow-up: +2.15 ± 0.13 servings per day Control: Baseline: +1.56 ± 0.18 servings per day Immediately after control: +1.72 ± 0.19 servings per day 2 months follow-up: 1.48 ± 0.19 servings per day
Lee (2010), Korea.	Case-control study	Case-control study	Conducted over 6 week period. Quiz-based learning for recommended intensity. Weight reduction was target 4kg a month to stay healthy. **SmartDiet:** Mobile-phone application. Analyzes daily nutrition intake. Analyzes daily nutrition intake and promotes knowledge about nutrition. **Control:** Not described	Diet Planner. Personalized nutrition information for food and activity. Diet game learning tool on how to control nutrition intake and exercise. Avatar. Simulate current and future body shape (based on weight).	Fat mass, weight and BMI. Mypage recorded daily calorie intake. Meal assessment calculated based on information from food and exercise database. Calorie requirements for exercise was calculated using stop-watch function on phone.	Fat mass decreased in the intervention group (+17.3 to +16.1 kg, $p<0.05$). Weight decreased in the intervention group (+58.5 to 5+6.6, kg, $p<0.05$) BMI decreased in the intervention group (+22.2 to +21.4 kg/m^2, $p<0.05$). No changes in the control group related to fat mass, weight and BMI.

RCT: Randomized Controlled Trial, FV: Fruit and Vegetables, SSB: Sugar-sweetened beverages, PA: Physical Activity.

Appendix 2. NAK Questionnaire

Nutrition Attitudes and Knowledge (NAK) Questionnaire

Number: ______________________

1. What does healthy eating mean to you?

____

____

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
2. Healthy eating should be an important part of my life	1	2	3	4	5
3. What I eat can affect my current health	1	2	3	4	5
4. My family thinks healthy eating is important	1	2	3	4	5
5. Eating healthy now can help me be healthy in the future	1	2	3	4	5

Drinks

6. What is the best thing to drink when you are thirsty?

a) Water b) Soft Drinks/pop c) Milk d) Unsweetened Soy Milk

7. Which drink should only be enjoyed once in a while?

a) Water ***b) Soft Drinks/Pop*** c) Milk d) Unsweetened Soy Milk

8. Dairy and unsweetened soy milk are a good source of which nutrients?

a) Vitamin A & B ***b) Calcium & Vitamin D*** c) Fibre & Vitamin C d) Sodium & Saturated Fat

9. Why is drinking water regularly important for your health?

a) Water contains vitamins and minerals that help you grow ***b) Water keeps your body hydrated***

c) Water is a good source of energy d) Water is a good source of fibre

10. Fruit juices, like orange and apple juice, are a sugary drink.

a) True b) False

Grains

11. Which type of grain foods should you choose most often?

a) Refined grain foods b) Millet grain foods ***c) Whole grain foods*** d) Wheat grain foods

12. Whole grain bread contains all 3 parts of the grain kernel (Bran, Endosperm and the Germ) – all of which play an important role in your health. Examples of whole grains include:

a) Quinoa b) Whole Grain Bread c) Flour Tortillas ***d) A&B***

13. Compared to white bread, whole grain bread is higher in which nutrient?

a) Sugar b) Sodium ***c) Fibre*** d) Saturated fat

14. Why is fibre an important nutrient for your health?

a) Fibre helps you feel full for longer b) Fibre gives you energy

c) Fibre keeps your digestive system healthy d) A&C

15. When grain foods are refined some parts are removed. What happens to the nutritional content of refined grains food when these parts are removed?

a) Fibre is added ***b) Vitamins, minerals and fibre are removed***

c) Vitamins and minerals are added d) There is no chance to the nutritional content

Appendix 2. Cont.

Vegetables & Fruits

16. Vegetables and fruits are a good source of _________.
a) Toxins ***b) Vitamins & minerals*** c) Protein d) Fat

17. Every day you should try to eat vegetables and fruits that are different _________.
a) Shapes b) Colours c) Textures ***d) All of the above***

18. What nutrient can you find in fruit that is *not* found in fruit juice?
a) Iron b) Vitamin C ***c) Fibre*** d) Calcium

19. How much of your plate should be vegetables and fruits?
a. ¼
b. 1/3
c. ½
d. ¾

20. When choosing canned or frozen vegetables and fruits, you should try to choose options that do not contain added _________.
a) Fibre & carbohydrates ***b) Sodium*** c) Vitamins & minerals d) Protein

Proteins

21. A diet high in which type of fat can cause heart disease?
a) Saturated fat b) Unsaturated fat c) Omega-3 fatty acids d) None of the above

22. What type of protein food should you eat more often?
a) Pork b) Chicken c) Beef ***d) Plant protein foods***

23. Which protein food is also a source of fibre?
a) Chicken ***b) Beans*** c) Beef d) Fish

24. Processed meats, like hot dogs and chicken nuggets, are high in which nutrients?
a) Sodium & saturated fat b) Fibre & carbohydrates
c) Sugar & water d) Omega-3 fatty acids & unsaturated fat

25. Which animal protein may contain unsaturated fats?
a) Steak ***b) Fish*** **c)** Milk d) Hot dogs

Appendix 3: Nutrition Attitudes and Knowledge Questionnaire: Canadian Nutrition Society Abstract

Abstract submitted to the 2021 Canadian Nutrition Society Annual Conference

Measuring children's knowledge of Canada's Food Guide: Nutrition Attitudes and Knowledge Questionnaire

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Background: Few engaging digital tools to support children's understanding of the 2019 Canada's Food Guide (CFG). While our research team developed a mobile serious game application (Foodbot Factory) to teach children about the CFG healthy eating principles, there are no measurement tools to assess children's knowledge of the CFG after using Foodbot Factory. **Objective:** To develop and validate a Nutrition Attitudes and Knowledge (NAK) questionnaire for assessing nutrition knowledge and nutrition attitudes. **Design:** Questionnaire items were created based on the 2019 CFG content and aligned with the four thematic subcomponents in Foodbot Factory (Drinks, Whole Grain Foods, Vegetables and Fruits, Protein Foods). Knowledge questions were multiple choice (20 points total, 5 points per subcomponent). Attitudes were evaluated using four 5-point Likert scale questions. Face and content validation of the NAK questionnaire were conducted among experts in nutrition and education. Experts rated the validity of questionnaire items on a 5-point Likert scale and provided narrative comments highlighting suggested modifications. Construct validity was assessed through a single-armed pre-post study among children 9-10 years of age who were in the same Grade 4 classroom. The NAK questionnaire was administered before and after using Foodbot Factory. Overall composite scores and individual scores for each subcomponent were assessed using paired t-tests. **Results:** Seven nutrition and education experts provided feedback on the face and content validity of the NAK questionnaire, which resulted in minor wording modifications, question conversion and the addition of two questions. After students (n=23) used Foodbot Factory there were statistically significant increases in overall nutrition knowledge (11.1 ± 2.6 to 14.3 ± 2.4, $p<0.001$), Whole Grain foods (2.6 ± 1.6 to 3.4 ± 1.0, $p=0.013$), Vegetables & Fruit (2.7 ± 1.2 to 3.6 ± 1.1, $p<0.001$) and Protein foods (2.1 ± 1.0 vs 3.2 ± 1.2. $p=0.003$). Knowledge of Drinks remained unchanged; however, baseline knowledge was high. There were no nutrition attitude changes, which were not expected given the short time period. **Conclusion:** The NAK questionnaire can be a useful and valid tool for assessing baseline and changes in nutrition knowledge related to the 2019 CFG guidelines. **Funding**: Ontario Research Fund – Research Excellence grant.

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