Research Square

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The effect of a digital curriculum-based nutrition education intervention on elementary school children's nutrition knowledge: the Foodbot Factory cluster randomized controlled trial

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Abstract

Background

School-based nutrition education is critical for developing children's food literacy. Despite nutrition education being mandatory in the curriculum, teachers face time, professional development and resource limitations that impede delivery. This study assessed whether a digital nutrition education intervention (Foodbot Factory: serious game + teacher lesson plans) would yield greater improvements in child nutrition knowledge and attitudes and be more acceptable among children than conventional nutrition education lessons (control).

Methods

In a cluster-randomized controlled trial, 32 Grade 4 and 4/5 classrooms in Ontario, Canada, were randomized 1:1 to the Foodbot Factory or control group. A trained teacher provided both groups with nutrition education for 35–40 minutes/day for five days. Nutrition knowledge was assessed at baseline, post-intervention, 4-week and 3-month follow-ups using a validated 20-item questionnaire. Overall knowledge was calculated as correct responses out of 20, with four food group sub-scores (protein foods, vegetables and fruit, whole grain foods, and drinks; five questions/group). Intervention acceptability was assessed post-intervention using eight items on a 5-point Likert scale. Linear mixed models assessed the treatment-by-time interaction effect using a complete-case analysis. Binary logistic regressions assessed intervention acceptability between groups.

Results

Compared to the control group (n = 260), the Foodbot Factory group (n = 255) had significantly greater increases in overall nutrition knowledge from baseline to post-intervention ($\beta = 2.7$; 95% CI [2.2, 3.2]; $p < 0.001$). Overall knowledge retention was significantly greater in the Foodbot Factory group than in the control group at the 4-week ($\beta = 2.0$; 95% CI [1.5, 2.4]; $p < 0.001$) and 3-month follow-ups ($\beta = 1.6$; 95% CI [1.1, 2.1]; $p < 0.001$). Knowledge retention of food group sub-scores over time was significantly greater for the Foodbot Factory group at both 4-weeks and 3-months for all food groups except drinks (all $p < 0.05$). Neither intervention significantly impacted children's nutrition attitudes, which were highly positive at baseline. The Foodbot Factory intervention was rated as more acceptable than the control, with participants being significantly more likely to rate Foodbot Factory as fun (87.8% vs. 76.4%; $p = 0.042$).

Conclusions

Using the Foodbot Factory intervention in classrooms was superior to conventional teaching methods in improving and retaining children's nutrition knowledge and was more acceptable.

Trial Registration:

ClinicalTrials.gov (NCT05979259), registered 08/07/2023.

Introduction

Food literacy – the interrelated attributes of food and nutrition knowledge, food preparation skills, and attitudes that interact with the food environment to shape our individual dietary choices [1] – is associated with reduced risk of chronic disease and better overall diet quality in both adults and children [2–5]. Among children, higher food literacy is associated with increased consumption of vegetables and fruit and decreased consumption of sugary drinks [6, 7]. However, current estimates indicate that Canadians have low to moderate levels of food literacy [8–10], highlighting that public health efforts should prioritize improving population food literacy as a key strategy to improve diet quality.

Childhood is a critical time for developing and establishing food literacy [11], with longitudinal studies demonstrating that childhood dietary behaviours often track into adulthood [12]. Children spend the majority of their waking hours at school; therefore, schools are well positioned to support food literacy development, providing opportunities to engage children through curriculum-based learning. For instance, a systematic review and meta-analysis demonstrated that teacher-delivered nutrition education improved children's nutrition knowledge and dietary habits, with experiential learning approaches, such as school gardens and cooking classes, being the most effective [13, 14]. In Canada, nutrition is embedded within mandated provincial and territorial curricula. However, teachers consistently face challenges in implementing high-quality nutrition education, including limited instructional time for nutrition, insufficient professional development, and a lack of evidence-based, curriculum-aligned teaching resources [15–17]. These barriers limit the effective delivery of nutrition education in classrooms.

A recent systematic review of documents evaluated a range of school-based nutrition education interventions examined in the Canadian context [18]. The interventions included nutrition education provided by teachers or external facilitators, school food provision programs, school gardens and multi-component interventions that combined different strategies [18]. This review found heterogeneity in the types of interventions studied and that the nutrition education interventions evaluated were not always aligned with the curriculum, which has been identified as a barrier to intervention implementation in other school-based studies [18–20]. Furthermore, many of the studies had a moderate-to-high risk of bias and short follow-up periods, making it difficult to draw conclusions on the effectiveness of the interventions and their long-term impacts [18]. Collectively, these findings highlight the need for more high-quality evidence related to curriculum-based nutrition education interventions that are effective in improving children's food literacy.

To address gaps in existing nutrition education interventions, we developed Foodbot Factory, a curriculum-aligned digital food literacy intervention for children in Grades 4 and 5 (ages 8–12 years). The intervention has two components. The first component of the Foodbot Factory intervention is a digital serious game (e.g., a digital game for educational purposes) that teaches about Canada's Food Guide (CFG), Canada's

national health eating guidelines that are integrated into provincial and territorial curricula [21–23]. Serious games allow children to learn by doing, where they can make their own choices in the game, receive feedback on those choices and have repeated exposure to opportunities to apply their knowledge [24, 25]. This is a form of experiential learning that is effective and leverages increasing access to technology in classrooms [26, 27]. Systematic and scoping reviews indicate that serious games are effective in improving both children's nutrition knowledge and dietary habits [27, 28]. The second component is teacher-led lesson plans that include classroom activities to activate children's prior nutrition knowledge, reinforce serious game content, support reflection and connect learning from the game to their lived experiences [29–31]. Foodbot Factory underwent rigorous, iterative co-design and testing by an interdisciplinary team of dietitians, teachers, computer scientists, academics and public health interest holders [29–31]. The intervention was designed to be flexible, inclusive and accessible including features within the serious game, such as audio voiceovers, re-playable dialogue, adjustable text size and volume for background music, sounds and voiceovers [32]. The teacher materials provide guidance on addressing food insecurity, cultural foods and in using food-neutral language [31]. Our pilot study conducted in a mock classroom environment demonstrated that children who played the Foodbot Factory serious game for five consecutive days significantly improved their nutrition knowledge compared to children who played a nutrition-focused game available on the app marketplace (control) [9]. However, this study evaluated the serious game alone and was conducted outside classrooms with a small, non-representative sample of children [9]. Thus, we needed to evaluate the Foodbot Factory intervention, including the game and lesson plans, in diverse classroom environments.

Therefore, the objective of this study was to determine if the Foodbot Factory intervention is superior to conventional teaching methods in improving children's nutrition knowledge and attitudes. A secondary objective was to assess children's acceptability of the Foodbot Factory intervention compared with conventional teaching methods. We hypothesized that children in classrooms randomized to learn using the Foodbot Factory intervention would demonstrate greater improvements in, and retention of, their nutrition knowledge and attitudes, and that the intervention would be more acceptable compared to children in classrooms randomized to the control group.

Methods

Trial Design

This study used a two-arm, single-blinded, parallel cluster-randomized controlled trial (cRCT) design, conducted from October 2023 to July 2025. Classroom clusters were allocated in a 1:1 ratio. The trial design was informed by a feasibility study, and the protocol has been previously published [33, 34]. The overall procedure for the trial is visualized in Fig. 1. Research ethics approval was obtained from the Ontario Tech University REB (File No. 17109) and from six school boards, and all participants provided consent/assent to participate. It was prospectively registered at ClinicalTrials.gov (NCT05979259) on 08/07/2023 and is reported according to the CONSORT guidelines (Supplementary File 1).

Participants and Setting

Thirty-two Grade 4 and 4/5 classrooms were recruited from participating school boards across South-Central, South-Eastern, and North-Western Ontario, Canada. For recruitment, schools were organized into quintiles based on their Fraser Institute school report card rankings [35], then randomly selected from each quintile. Principals of selected schools were then contacted by email and telephone. Schools were eligible to participate if they had at least one Grade 4 or 4/5 classroom. If willing to participate, the principal shared information about the study with the classroom teachers. Classrooms were eligible to participate if they had not yet covered the nutrition curriculum for that school year and had at least two-thirds of children in the classroom with parental consent to participate. All children in a classroom were eligible to participate in the study. Parental consent for child study participation was obtained through forms sent to parents/guardians by the classroom teacher before classrooms were randomized to their study groups. Assent from children with parental consent was obtained in the classroom by the study team after randomization but before receiving the intervention.

Interventions

Classrooms in both study groups received nutrition education lessons in their usual classrooms from a certified study teacher who was a member of the research team. The study teacher was trained by the research team to follow best practices for teaching children about nutrition, including using food-neutral language, and to adhere to a standardized research protocol that was established for each intervention, supporting high fidelity. Classrooms received a different nutrition education lesson for 35–40 minutes/day for five consecutive days. The duration and content of both interventions aligned with the Ontario curriculum requirements for nutrition [22], covering similar topics and learning goals, and using the three-phase lesson format that is commonly used by teachers [36]. While the Foodbot Factory intervention contained some additional teacher supports, the interventions were carefully designed to be comparable, with the primary difference between groups being the use of the Foodbot Factory serious game.

Foodbot Factory Intervention

Classrooms randomized to the Foodbot Factory group received nutrition education using the Foodbot Factory intervention, which includes a serious game and lesson plans organized into five nutrition lessons covering different food groups (drinks, whole grain foods, vegetables and fruit, animal protein foods, plant protein foods). The content of both the serious game and lesson plans has been described in detail elsewhere [29–31, 37]. Images of the serious game are available in Supplementary Fig. 1. Following the three-phase lesson structure [36], in the first phase, the nutrition topic for the lesson is introduced and learning expectations are set (5–10 minutes). In the second phase, children independently play one module of the Foodbot Factory serious game using tablets provided by the research team (10–15 minutes). In the third and final phase, children consolidate their learning and connect it to their lived experience through discussion and teacher-led activities (10 minutes).

Control Intervention

Classrooms randomized to the control group received nutrition education using conventional learning materials (i.e., activity sheets) sourced from a popular repository of teaching resources [38]. This approach was chosen to emulate “usual practices” in nutrition education, as teachers have reported using existing nutrition resources from online teaching repositories [15]. The learning materials for the control group were carefully selected by the interdisciplinary research team through co-design with practicing teachers and dietitians to ensure they were accurate, appropriate and aligned with both the curriculum and content covered in the Foodbot Factory intervention. The lesson plans for the control group were co-designed to follow the same three-phase lesson format as the Foodbot Factory intervention and use similar activities in the first and third phases to discuss the nutrition topic and consolidate learning [36].

Data Collection and Outcome Assessment

Outcome Assessment

The primary outcome, change in overall nutrition knowledge, was measured using the Nutrition Attitudes and Knowledge (NAK) questionnaire, which also assessed sub-scores of food-group specific nutrition knowledge and nutrition attitudes (secondary outcomes). The NAK questionnaire has been assessed for face and content validity and is sensitive to detecting changes in children’s nutrition knowledge of CFG healthy food choice recommendations [9, 39]. The NAK was administered at baseline and immediately post-intervention (day 5), with retention assessed at 4-week and 3-month follow-ups. The NAK consists of 20 multiple-choice knowledge questions with total scores ranging from 0 to 20 (1 point per correct response). Questions are equally distributed across four food group categories that include vegetables and fruit, whole grain foods, protein foods, and drinks, and sub-scores were calculated as the number of correct responses out of the corresponding five questions within each category. The NAK questionnaire also contained four questions evaluating nutrition attitudes on a 5-point Likert scale (1 = strongly disagree; 5 = strongly agree), which were summed together to create a continuous nutrition attitudes score with a maximum score of 20.

The secondary outcome of intervention acceptability was assessed using an acceptability questionnaire that was developed and assessed for content validity by experts, based on the Theoretical Framework of Acceptability (TFA) [40]. The questionnaire included 10-items on a 5-point Likert scale (1 = strongly disagree; 5 = strongly agree), with each item measuring a different component of intervention acceptability (e.g., affective attitude, burden, participant experience). Two items on the questionnaire were removed from the final analysis due to low internal consistency. One item assessed risk of harm by asking participants if the intervention caused feelings of sadness and stress about food and nutrition. Each item on the acceptability questionnaire was reported separately.

Both the NAK and acceptability questionnaires were administered to children in their classrooms by a blinded outcome assessor. Children were instructed to complete the questionnaire independently, using

paper and pencil to circle their responses. To support NAK completion, the outcome assessor projected the questionnaire items onto a screen in front of the classroom and read each question aloud twice.

Covariates

Parents completed a 15-item demographic questionnaire to document covariates that may impact study outcomes. The study teacher completed structured field notes each day of the intervention to document protocol fidelity and participant absences.

Sample Size, Randomization and Allocation

The sample size was calculated at 14 classrooms per group, assuming an average of 18 participants in each classroom cluster, to provide 80% power at the significance level of 0.05 to detect changes in the primary outcome of overall nutrition knowledge with effect sizes between 0.15 and 0.50 [41]. This calculation considered an intraclass correlation coefficient ranging from 0.05 to 0.30 based on existing literature [42, 43]. Anticipating an attrition rate of 15% at the 3-month follow-up, we recruited two additional classrooms per group for a total of 32 classrooms to ensure sufficient power [44].

A web-based data management system, REDCap, was used to conduct classroom randomization after baseline data collection [45]. A blocked random allocation sequence was generated by personnel not involved in the trial, using a random number generator and a block size of two. Pair-matching randomization was used, where two classrooms in the same school or area were matched together to balance neighbourhood-level factors between groups [46]. Randomization was completed the day before intervention delivery by study personnel who were not involved in outcome assessment. The allocation sequence was concealed until the end of the trial [45].

Statistical Analysis

Descriptive statistics were used to summarize participant demographics, nutrition knowledge, nutrition attitudes and intervention acceptability. Continuous data were presented as means and standard deviations, while categorical data were presented as counts with percentages. Linear mixed models assessed changes from baseline, post-intervention, 4-week follow-up and 3-month follow-up in overall nutrition knowledge, nutrition knowledge sub-scores and nutrition attitudes between groups, accounting for individual and classroom correlations using a complete-case analysis [47]. Both an intention-to-treat analysis and a per-protocol analysis were conducted. The linear mixed models adjusted for the intervention group, classroom grade, age, gender, time and the treatment-by-time interaction. Considering high baseline knowledge for the drinks sub-score compared to other sub-scores, an analysis of overall nutrition knowledge was conducted, including questions on protein foods, whole grain foods and vegetables and fruit, to ascertain the impacts of the intervention where baseline knowledge was low (total out of 15). Items on the acceptability questionnaire were dichotomized as “acceptable” (scores of 4 and 5) and “not acceptable” (scores of 1, 2 and 3). Binary logistic regression was used to compare the acceptability of each item between groups, accounting for clustering and adjusting for multiple comparisons using the false-detection rate method [48].

Sensitivity analyses of the linear mixed models assessing changes in nutrition knowledge and attitudes were conducted using multiple imputation with chained equations (MICE) [49]. In addition, a sensitivity analysis was conducted to remove four classrooms in the study that experienced protocol deviations in intervention delivery due to snow day disruptions, where classrooms received all five lessons over the course of two weeks instead of one week. This sensitivity analysis allows us to assess if these deviations impacted intervention effectiveness. Sub-group analyses by gender were conducted using only boys and girls, as there was an insufficient sample size of children identifying as a gender minority. For all nutrition outcomes (overall, subgroups, attitudes), likelihood ratio tests using a significance level of 0.05 were used to compare to a more complex covariate specification that allowed for a three-way interaction effect between gender, treatment and timepoint. To examine gender differences in intervention accessibility, a binary logistic regression was conducted between boys and girls both within and between groups, including interaction effects. All statistical analyses were completed in RStudio version 4.5.2 (Posit Software, PBC).

Results

Baseline Characteristics of Study Participants

A total of 32 classrooms participated in the study, with the majority of classrooms located in South-Central Ontario (n = 24, 75%), the most populous region of the province, followed by more rural locations in South-Eastern Ontario (n = 6, 19%) and North-Western Ontario (n = 2, 6%). Classrooms were from rural, small population centres (n = 16, 50%), suburban, medium population centres (n = 6, 19%) and urban, large population centres (n = 10, 31%). Most participating classrooms were Grade 4 classrooms (n = 20, 62%), with the remaining being Grade 4/5 split classrooms (n = 12, 38%). The mean Fraser Institute score was 6.3 (range = 3.0-7.7), which indicates school academic performance with a range from 0–10 and a provincial average of 6.0 [35]. School level student demographics also varied, with an average 8% (range = 0–32%) of students being English language learners, 15% (range = 5–26%) of students receiving special education services and 7% (range = 0–15%) of students from lower-income households [50]. Baseline characteristics of individual participants were similar between groups (Table 1). A total of 605 children from participating classrooms were recruited, of whom 515 had completed outcome assessments at all four timepoints and were included in our intention-to-treat analysis (Fig. 2). Among children who had all outcome assessments at all four timepoints, 415 were present for all five intervention days and were included in the per-protocol analysis.

Table 1
Participant demographic characteristics at baseline.

Demographic Characteristic	Overall (n = 515)	Foodbot Factory Group (n = 255)	Control Group (n = 260)
Age (Years)	9.2 ± 0.5	9.2 ± 0.5	9.2 ± 0.5
Grade			
4	433 (84%)	217 (85%)	216 (83%)
5	82 (16%)	38 (15%)	44 (17%)
Gender			
Boy	220 (43%)	113 (44%)	107 (41%)
Girl	266 (52%)	127 (50%)	139 (53%)
Gender minority	2 (< 1%)	1 (< 1%)	1 (< 1%)
Prefer not to answer	27 (5%)	14 (5%)	13 (5%)
Household Income ($CAD; n = 467)			
<$30,000	15 (3%)	6 (3%)	9 (4%)
$30,000 – $59,000	34 (7%)	18 (8%)	16 (7%)
$60,000 – $99,000	60 (13%)	36 (15%)	24 (10%)
$100,000 +	261 (56%)	130 (55%)	131 (56%)
Do not know/Prefer not to answer	97 (21%)	45 (19%)	52 (23%)
Parent Education (n = 469)			
High school or less	46 (10%)	30 (13%)	16 (7%)
College/Trades	156 (33%)	83 (35%)	73 (31%)
Undergraduate degree	142 (30%)	63 (27%)	79 (34%)
Graduate/Professional degree	104 (22%)	50 (21%)	54 (23%)
Prefer not to answer	21 (5%)	10 (4%)	11 (5%)
Food Insecurity Screening (n = 465)			
Would run out of food	52 (11%)	26 (11%)	25 (11%)
Food does not last	27 (6%)	15 (6%)	12 (5%)
Child Race/Ethnicity (n = 433)			
Black	23 (5%)	10 (5%)	13 (6%)
East Asian	11 (2.5%)	5 (2%)	6 (3%)

Demographic Characteristic	Overall (n = 515)	Foodbot Factory Group (n = 255)	Control Group (n = 260)
Indigenous	6 (1%)	4 (2%)	2 (1%)
Latino	3 (1%)	1 (1%)	2 (1%)
Middle Eastern	10 (2%)	5 (2%)	5 (2%)
Mixed Race	44 (10%)	20 (9%)	24 (11%)
Other	4 (1%)	3 (1%)	1 (1%)
South Asian	52 (12%)	29 (13%)	23 (11%)
Southeast Asian	12 (3%)	2 (1%)	10 (5%)
White	268 (62%)	140 (64%)	128 (60%)
Child with a Diagnosed Disability (n = 461)	63 (14%)	29 (13%)	34 (15%)
Child with a Dietary Restriction (n = 456)	49 (11%)	28 (12%)	21 (9.3%)

[1]Values are mean ± (SD) for continuous variables and n (%) for categorical variables. Parent-reported variables have varying sample sizes due to missing demographic surveys and skipped questions.

Overall Nutrition Knowledge

Table 2 presents the unadjusted means and the treatment-by-time interaction effect between groups for nutrition knowledge and attitudes using both the intention-to-treat and per-protocol analyses. The intra-cluster correlation coefficient for overall nutrition knowledge was 0.08. An item-by-item summary of correct responses at each timepoint is provided in Supplementary Table 1. While both groups demonstrated improvements in their overall nutrition knowledge, the intention-to-treat analysis showed that children in classrooms in the Foodbot Factory group had significantly greater increases in their overall nutrition knowledge from baseline to post-intervention ($\beta = 2.7$; 95% CI [2.2, 3.2]; $p < 0.001$), which was similar to the per protocol analysis ($\beta = 2.9$; 95% CI [2.4, 3.4] $p < 0.001$). In other words, in the intention-to-treat analysis the Foodbot Factory group improved their knowledge from 55% to 77%, while the control group improved their knowledge from 54% to 62%. In the per-protocol analysis, the Foodbot Factory group improved from 55% to 78% and the control group from 55% to 63%. Overall knowledge retention over time was also greater in the Foodbot Factory group compared to the control group at both the 4-week ($\beta = 2.0$; 95% CI [1.5, 2.4]; $p < 0.001$) and the 3-month follow-ups ($\beta = 1.6$; 95% CI [1.1, 2.1]; $p < 0.001$). In the analysis of overall nutrition knowledge excluding drinks (total score out of 15), even greater statistically significant effect sizes were observed for the Foodbot Factory group compared to the control group at post-intervention ($\beta = 2.5$; 95% CI [2.1, 3.0]; $p < 0.001$), 4-week follow-up ($\beta = 1.8$; 95% CI [1.3, 2.2]; $p < 0.001$) and 3-month follow-up ($\beta = 1.5$; 95% CI [1.1, 1.9]; $p < 0.001$). This represents an increase in nutrition knowledge in the Foodbot Factory group from 48% at baseline to 73% post-intervention compared to 46% to 56% in the control group.

Table 2
Nutrition knowledge and attitudes, unadjusted means, and treatment by time interaction effect between groups.

Time Point	Intention-to-Treat Analysis				Per-Protocol Analysis			
	Foodbot Factory Group (n = 255)	Control Group (n = 260)	Treatment x Time Interaction (β, 95% CI)	p-value	Foodbot Factory Group (n = 205)	Control Group (n = 210)	Treatment x Time Interaction (β, 95% CI)	p-value
Overall Nutrition Knowledge								
Baseline	11.04 ± 2.48	10.89 ± 2.56	Reference		10.97 ± 2.40	10.92 ± 2.65	Reference	
Post-Intervention	15.34 ± 3.13	12.48 ± 3.07	2.7 (2.2, 3.2)	< 0.001	15.55 ± 3.14	12.59 ± 2.88	2.9 (2.4, 3.4)	< 0.001
4-weeks	14.37 ± 3.08	12.25 ± 3.04	2.0 (1.5, 2.4)	< 0.001	14.50 ± 3.17	12.32 ± 2.98	2.1 (1.6, 2.6)	< 0.001
3-months	14.00 ± 3.20	12.25 ± 3.21	1.6 (1.1, 2.1)	< 0.001	14.12 ± 3.28	12.25 ± 3.18	1.8 (1.3, 2.3)	< 0.001
Protein Foods								
Baseline	2.05 ± 1.11	2.19 ± 1.19	Reference		2.05 ± 1.10	2.21 ± 1.21	Reference	
Post-Intervention	3.43 ± 1.29	2.28 ± 1.30	1.3 (1.0, 1.5)	< 0.001	3.55 ± 1.27	2.25 ± 1.28	1.5 (1.2, 1.7)	< 0.001
4-weeks	2.89 ± 1.28	2.25 ± 1.27	0.8 (0.5, 1.0)	< 0.001	2.93 ± 1.32	2.26 ± 1.30	0.8 (0.6, 1.1)	< 0.001
3-months	2.84 ± 1.25	2.27 ± 1.27	0.7 (0.5, 0.9)	< 0.001	2.89 ± 1.29	2.23 ± 1.27	0.8 (0.5, 1.1)	< 0.001
Whole Grain Foods								
Baseline	2.27 ± 1.16	2.23 ± 1.13	Reference		2.24 ± 1.14	2.23 ± 1.15	Reference	
Post-Intervention	3.82 ± 1.30	3.11 ± 1.36	0.7 (0.4, 0.9)	< 0.001	3.89 ± 1.24	3.18 ± 1.31	0.7 (0.4, 1.0)	< 0.001
4-weeks	3.64 ± 1.33	2.97 ± 1.35	0.6 (0.4, 0.9)	< 0.001	3.67 ± 1.34	3.02 ± 1.34	0.6 (0.4, 0.9)	< 0.001
3-months	3.44 ± 1.44	2.92 ± 1.40	0.5 (0.3, 0.7)	< 0.001	3.51 ± 1.45	2.96 ± 1.39	0.5 (0.3, 0.8)	< 0.001
Vegetables & Fruit								

Time Point	Intention-to-Treat Analysis				Per-Protocol Analysis			
	Foodbot Factory Group (n = 255)	Control Group (n = 260)	Treatment x Time Interaction (β, 95% CI)	p-value	Foodbot Factory Group (n = 205)	Control Group (n = 210)	Treatment x Time Interaction (β, 95% CI)	p-value
Overall Nutrition Knowledge								
Baseline	2.81 ± 1.05	2.57 ± 1.06	Reference		2.78 ± 1.05	2.58 ± 1.08	Reference	
Post-Intervention	3.77 ± 1.01	2.95 ± 1.08	0.6 (0.4, 0.8)	< 0.001	3.77 ± 1.01	3.01 ± 1.04	0.6 (0.3, 0.8)	< 0.001
4-weeks	3.58 ± 1.04	2.99 ± 1.08	0.4 (0.2, 0.6)	< 0.001	3.63 ± 1.00	3.01 ± 1.08	0.4 (0.2, 0.6)	< 0.001
3-months	3.50 ± 1.06	2.96 ± 1.06	0.3 (0.1, 0.5)	< 0.001	3.53 ± 1.06	3.00 ± 1.04	0.3 (0.1, 0.6)	0.002
Drinks								
Baseline	3.92 ± 0.88	3.90 ± 0.80	Reference		3.90 ± 0.90	3.91 ± 0.80	Reference	
Post-Intervention	4.33 ± 0.72	4.14 ± 0.78	0.2 (0.03, 0.3)	0.022	4.35 ± 0.72	4.16 ± 0.78	0.2 (0.03, 0.4)	0.022
4-weeks	4.25 ± 0.72	4.04 ± 0.81	0.2 (0.05, 0.4)	0.010	4.23 ± 0.73	4.02 ± 0.81	0.2 (0.05, 0.4)	0.011
3-months	4.20 ± 0.78	4.10 ± 0.83	0.09 (-0.1, 0.2)	0.264	4.20 ± 0.80	4.07 ± 0.85	0.1 (-0.03, 0.3)	0.113
Nutrition Attitudes								
Baseline	17.95 ± 1.86	17.79 ± 1.91	Reference		17.91 ± 1.85	17.83 ± 1.91	Reference	
Post-Intervention	18.21 ± 1.92	18.07 ± 2.00	-0.01 (-0.3, 0.3)	0.941	18.19 ± 1.96	18.03 ± 2.10	0.08 (-0.2, 0.4)	0.635
4-weeks	17.99 ± 2.12	18.08 ± 1.86	-0.2 (-0.5, 0.1)	0.110	18.00 ± 2.14	18.07 ± 1.86	-0.2 (-0.5, 0.2)	0.335
3-months	18.08 ± 2.12	17.88 ± 2.19	0.04 (-0.2, 0.3)	0.778	18.11 ± 2.13	17.86 ± 2.28	0.2 (-0.2, 0.5)	0.336

Values are presented as unadjusted means ± standard deviations (SD). Treatment-by-time interaction effects (β) and 95% confidence intervals (CI) were estimated using linear mixed models. Intention-to-treat analyses included all randomized participants with complete data at all four time points. Per-protocol

analyses included all randomized participants with complete data who were present for the entire duration of the intervention.

Nutrition Knowledge Food Group Sub-Scores

When evaluating knowledge of specific food groups, compared to the control group, the Foodbot Factory group had significantly higher knowledge of protein foods (β = 1.3; 95% CI [1.0, 1.5]; p < 0.001), whole grain foods (β = 0.7; 95% CI [0.4, 0.9]; p < 0.001) and vegetables and fruit (β = 0.6; 95% CI [0.4, 0.8]; p < 0.001) from baseline to post-intervention. The treatment-by-time interaction effect remained statistically significant for knowledge of protein foods, whole grain foods, and vegetables and fruit at the 4-week and 3-month follow-ups, indicating that knowledge retention was consistently higher at each timepoint in the Foodbot Factory group, compared to the control group (Table 2). For both groups, knowledge of drinks was high at baseline. Small, albeit statistically significant increases in drinks knowledge from baseline to post-intervention were observed for the Foodbot Factory group compared to the control group (β = 0.2; 95% CI [0.03, 0.3]; p = 0.022); however, this difference was no longer statistically significant after three months (Table 2).

Nutrition Attitudes

Children in both study groups reported high nutrition attitudes at baseline (Table 2). As such, there were few meaningful changes in attitudes from baseline to post-intervention between the study groups (β = -0.01; 95% CI [-0.3, 0.3]; p = 0.941), a finding that was consistent at the 4-week or 3-month follow-ups. The mean response for each attitude question by group at each time point is presented in Supplementary Table 2.

Intervention Acceptability

At the end of the intervention period, both the Foodbot Factory and control interventions were rated as highly acceptable by children (Table 3). However, agreement for each item was consistently higher in the Foodbot Factory group (item acceptability range: 78.8% to 91.0%) compared to the control group (item acceptability range: 72.5% to 86.9%). Compared to the control group, the Foodbot Factory group was significantly more likely to agree that the intervention was fun (87.8% vs. 76.4%; p = 0.042). Few children reported sadness or stress in both the intervention (strongly agree = 3 [1.3%], agree = 7 [2.9%], neutral = 33 [13.8%], disagree = 46 [19.2%], strongly disagree = 151 [62.9%]) and control groups (strongly agree = 8 [3.3%], agree = 10 [4.1%], neutral = 32 [13.1%], disagree = 48 [19.6%], strongly disagree = 147 [60.0%]). Classroom teachers followed up with all participants who selected a response indicating sadness or stress (i.e., a response of strongly agree or agree). One adverse event was reported during this follow-up, but there were no direct concerns associated with either intervention and no protocol modifications were required.

Table 3
Comparison of intervention acceptability between the Foodbot Factory and control groups.

Acceptability Item	Foodbot Factory Group (n = 255)	Control Group (n = 260)	Odds Ratio (95% CI)	p-value
Perceived importance of learning about food and nutrition	232 (91.0%)	226 (86.9%)	1.5 (0.8, 2.8)	0.26
Perceived learning from the intervention	232 (91.0%)	219 (84.2%)	1.9 (1.0, 3.4)	0.15
The intervention was fun	224 (87.8%)	199 (76.4%)	2.2 (1.3, 3.8)	0.042
The goals of the intervention were clear	221 (86.7%)	205 (78.7%)	1.8 (1.0, 3.0)	0.15
Participating in the intervention was a positive experience	216 (84.7%)	200 (77.1%)	1.6 (1.0, 2.7)	0.18
There were no barriers to participating in the intervention	211 (82.7%)	196 (75.5%)	1.5 (0.9, 2.6)	0.20
Felt confident participating in the intervention	211 (82.7%)	200 (77.1%)	1.4 (0.9, 2.4)	0.26
It was easy to participate in the intervention	201 (78.8%)	189 (72.5%)	1.4 (1.0, 2.7)	0.1

Values are presented as the number and percentage of participants who agreed or strongly agreed with each acceptability item. Odds ratios (OR) with 95% confidence intervals (CI) were estimated using binary logistic regression, accounting for clustering at the classroom level. P-values were adjusted for multiple comparisons using the false-detection rate method.

Sensitivity & Sub-Group Analyses

Sensitivity analyses using MICE yielded similar results to the intention-to-treat analysis that used a complete case analysis approach, indicating the robustness of the findings (Supplementary Table 3). In the sensitivity analysis for protocol deviations, similar results to the primary analysis were found, indicating that disruptions in intervention delivery did not significantly impact the intervention's effectiveness (Supplementary Table 4).

For the sub-group analyses by gender, the likelihood ratio tests were statistically insignificant, indicating that overall nutrition knowledge, nutrition knowledge sub-scores and nutrition attitudes were not significantly different between genders (Supplementary Table 5). Regarding intervention acceptability, there were no statistically significant differences observed by gender, nor did intervention effects significantly differ by gender after adjusting for multiple comparisons (Supplementary Table 6).

Discussion

This cRCT examined the efficacy of Foodbot Factory, a novel, digital curriculum-based intervention, compared to conventional nutrition education materials for improving nutrition knowledge and attitudes among children in Grade 4 and 4/5 classrooms in Ontario, Canada. Our findings demonstrate that the Foodbot Factory intervention was superior in improving overall nutrition knowledge and knowledge of protein foods, whole grain foods, and vegetables and fruit compared to conventional teaching methods. Importantly, the Foodbot Factory intervention was also more effective in supporting retention of overall nutrition knowledge 4-weeks and 3-months after the intervention. Although participants in both groups improved their overall nutrition knowledge, the improvements demonstrated in the control group may reflect the typical benefits of curriculum-based nutrition education, whereas the Foodbot Factory intervention provided significantly greater learning benefits and knowledge gains. Neither intervention improved knowledge of drinks or nutrition attitudes; however, baseline scores for these outcomes were high, suggesting a ceiling effect and limiting the intervention's ability to have a substantive impact on these outcomes. The Foodbot Factory intervention also had higher acceptability ratings than the conventional teaching materials used for the control group, highlighting the importance of using engaging and interactive methods in the classroom to facilitate the acquisition and retention of nutrition knowledge. Furthermore, there were no significant differences in the acquisition and retention of nutrition knowledge and attitudes, or in intervention acceptability, between boys and girls. Overall, these findings support our hypothesis that Foodbot Factory would produce greater improvements in and retention of nutrition knowledge than conventional teaching materials, possibly due to the engaging and experiential learning opportunities offered by the serious game.

Our findings add to the growing body of literature demonstrating that serious games are effective tools for nutrition education, leading to improvements in and retention of knowledge beyond conventional teaching methods [51]. For example, *VitaVillage*, provided one hour of nutrition education using a serious game alone to children in Australia and improved knowledge from 66% to 69% [52], while the *Kids Obesity Prevention Program* in Germany combined a serious game and parent participation over 1.5 hours and improved knowledge from 46% to 66% [53]. Although direct comparison across studies should be interpreted with caution due to differences in intervention designs and outcomes, the Foodbot Factory intervention improved knowledge from 55% to 77%, demonstrating improvements in knowledge comparable to, or greater than, those reported in previous studies [52–54]. The magnitude of improvement in overall nutrition knowledge is a meaningful educational outcome considering it was achieved through a brief intervention and that nutrition knowledge is a fundamental component of food literacy [1]. In our previous pilot study, the Foodbot Factory serious game alone improved nutrition knowledge from 52% to 68% [9]. The greater overall improvement in nutrition knowledge in the current trial suggests that the complete Foodbot Factory intervention (serious game and lesson plans) enhanced learning, likely by having a teacher lead additional learning activities that introduce nutrition topics to the classroom, activate prior knowledge before playing the game, and support the consolidation of what was learned in the game by creating connections to lived experiences [31]. Our findings also add to the existing literature by addressing limitations of previous serious game studies, which are often conducted with small, non-representative samples [51]. By including schools from different regions of Ontario that varied in culture and rurality, this study provides evidence that Foodbot Factory can effectively improve nutrition knowledge across a broad range of classroom settings.

Neither the Foodbot Factory intervention nor the control intervention improved knowledge of the drinks food group and nutrition attitudes. High baseline scores for both outcomes suggest a ceiling effect, possibly influenced by the brief measures used to assess these constructs. The absence of an effect on knowledge of drinks is consistent with a previous Canadian study that found children in a similar age group had high knowledge of the nutritional aspects of drinks [6]. Together, these findings suggest that future nutrition education interventions may benefit from placing greater emphasis on broader food literacy concepts for drinks (e.g., their environmental impacts) [6]. Similarly, neither intervention in our study improved nutrition attitudes, which were also high at baseline. This finding contrasts with previous studies that found improved nutrition attitudes following longer interventions (8 to 12 consecutive weeks) [55, 56], suggesting that intervention duration, combined with a brief measure of attitudes, may have contributed to the lack of observed change.

Beyond improving children's nutrition knowledge, these findings have important implications for nutrition education in classrooms, as they demonstrate that a practical tool can support the dissemination of healthy eating guidelines in routine teaching practice. Although nutrition is part of provincial and territorial curricula, and CFG is intended to support nutrition education, teachers consistently report time and resource barriers to teaching it [15]. For example, CFG has a toolkit for educators, but the toolkit activities are not explicitly tied to the curriculum and frequently require 30 minutes or more of teacher preparation time, which does not address teacher-reported barriers [57]. In contrast, the design, content and features of the Foodbot Factory intervention were intentionally chosen to address teacher time and resource barriers. The intervention leverages the engaging and accessible opportunities offered by serious games and the teacher-led lesson plans, ultimately serving as a pragmatic intervention that requires minimal teacher preparation and supports the delivery of nutrition education within real-world classrooms. Their alignment with both the curriculum and the CFG also provides a mechanism for the national dissemination of national dietary guidelines to younger audiences in school settings. This is particularly relevant in the context of Canada's National School Food Policy, which recognizes the critical role schools play in fostering children's health and encourages the use of educational activities to support learning about CFG [58]. Importantly, the intervention was effective for both boys and girls, which is an encouraging finding considering that our previous research indicated differences in how boys and girls interact with nutrition content and that the intervention was carefully designed to be engaging for different genders [29]. Although the control group did not have the same magnitude of change in their nutrition knowledge, their overall nutrition knowledge did increase, highlighting the importance of co-designing nutrition interventions [59]. Furthermore, the Foodbot Factory intervention was highly accepted by participants, a key driver of the effectiveness of nutrition education interventions that may further support real-world implementation [15, 31, 59]. Consistent with previous research in school-based settings [60], additional implementation strategies to support the adoption and long-term sustainability of Foodbot Factory will be needed. Identifying and evaluating these strategies is the focus of our ongoing research.

Study Limitations

While this study had several strengths, including its randomized design, large sample size, inclusion of classrooms from diverse regions of Ontario, and optimization of study protocols through a previous

feasibility study [34], there are some key limitations to be considered. Although the interventions were provided by a trained study teacher to increase study feasibility and to facilitate recruitment (at the request of school boards), this approach may limit the external generalizability of the findings to routine classroom practice [15]. Additionally, the study teacher was not blinded to group allocation and provided the intervention to both groups, which may have introduced bias in intervention delivery; however, fidelity monitoring procedures were implemented to minimize this risk. Future evaluations of Foodbot Factory provided by classroom teachers are needed to determine whether similar outcomes can be achieved under real-world conditions, and to identify the required implementation strategies (e.g., professional development supports, adaptation, audit and feedback) that support adoption and scalable, sustained use in diverse classrooms. Due to incomplete parent demographic surveys (91% response rate), linear mixed models were not adjusted for parent-reported covariates (e.g., child ethnicity, parent education and household income). Finally, this study was limited by a relatively short intervention and follow-up period, with classrooms receiving approximately three and a half hours of nutrition education in one week. This duration was chosen to align with the time teachers typically allot for a single lesson and the limited time teachers have available for nutrition education [15]. While outcomes were assessed up to three months after the intervention, a longer follow-up was not feasible within the school year. Future research should examine whether lengthening the intervention duration, spreading lessons over a longer period and including refresher sessions enhance knowledge acquisition and retention, as highlighted by a recent systematic review [51].

Implications

These findings indicate that serious games combined with teacher lesson plans can be integrated into curriculum-based nutrition education and provide an experiential learning approach that effectively improves and supports the retention of children's nutrition knowledge, a key component of food literacy [1]. While traditional experiential learning opportunities have used school gardens and cooking classes to provide nutrition education [13, 14], this study suggests that serious games can provide an effective, scalable and ready-to-use alternative that can be implemented with existing classroom resources. By addressing commonly reported barriers to teaching nutrition, Foodbot Factory has the potential to support the implementation of Canada's national dietary guidelines. Future research should continue to evaluate serious games that support children's food and health literacy development and how such interventions can be integrated into classroom and school environments to support equitable health promotion.

Conclusions

This study demonstrates that the Foodbot Factory intervention was superior to conventional teaching approaches in improving and retaining nutrition knowledge when used in Grade 4 and 4/5 classrooms. By combining a curriculum-based serious game with teacher-led lesson plans, the intervention addresses important barriers to delivering nutrition education in schools and provides a fun and practical way to support the dissemination of Canada's Food Guide and the development of child food literacy. These findings demonstrate the potential of serious games to support nutrition education and healthy eating among children.

Abbreviations

CFG
Canada's Food Guide
cRCT
cluster randomized controlled trial
NAK
Nutrition Attitudes and Knowledge
MICE
multiple imputation with chained equations

Declarations

Human Ethics Approval and Consent to Participate

Research ethics approval was obtained at Ontario Tech University REB (File No. 17109) and at six school boards. All child participants had parental consent and provided assent to participate.

Consent for Publication

Not applicable.

Availability of Data and Materials

Data will be made available to researchers upon reasonable request through an anonymized online repository.

Competing Interests

The authors declare that they have no competing interests.

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Authors' Contributions

JMB, BF-A and JA conceived the project. JMB, ST, BF-A, AL, JH, BK, WL, EV, MF, CT-L and JA were involved in the design of the study. JA, JMB, BF-A, AL, JH and BK were involved in the design of the intervention materials. JA, KJ and ST were involved in data collection. WL contributed to the statistical analysis plan. EK and JMB conducted the statistical analysis. JMB wrote the first draft of the manuscript. All authors (JMB, KJ, EK, ST, BF-A, AL, JH, BK, WL, EV, MF, CT-L and JA) approved the final manuscript. JA is the corresponding author and guarantor of this manuscript.

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Figures

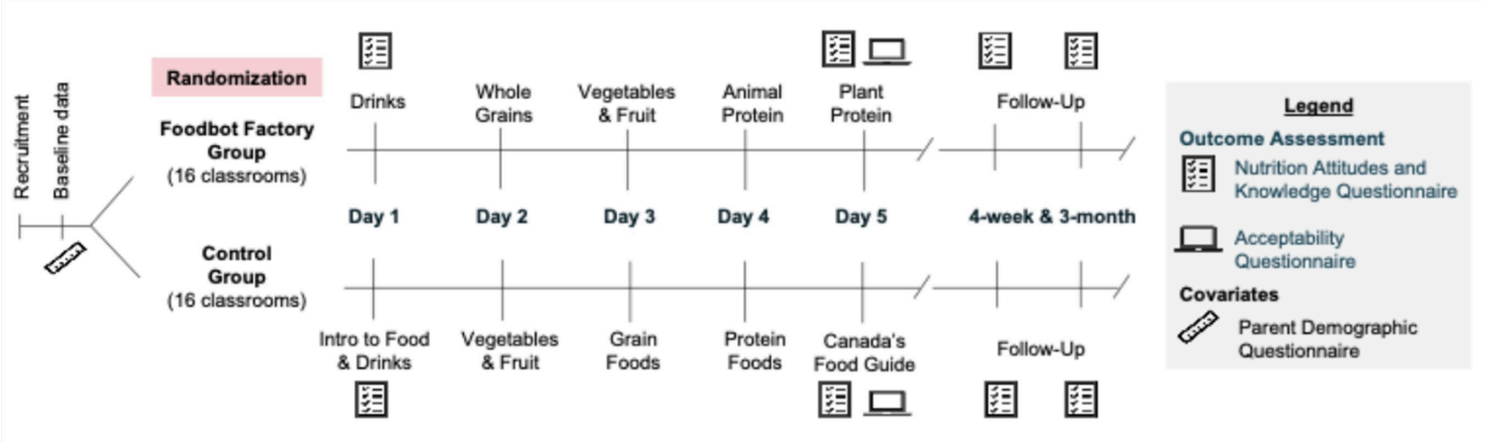

Figure 1

Foodbot Factory cRCT Procedure.

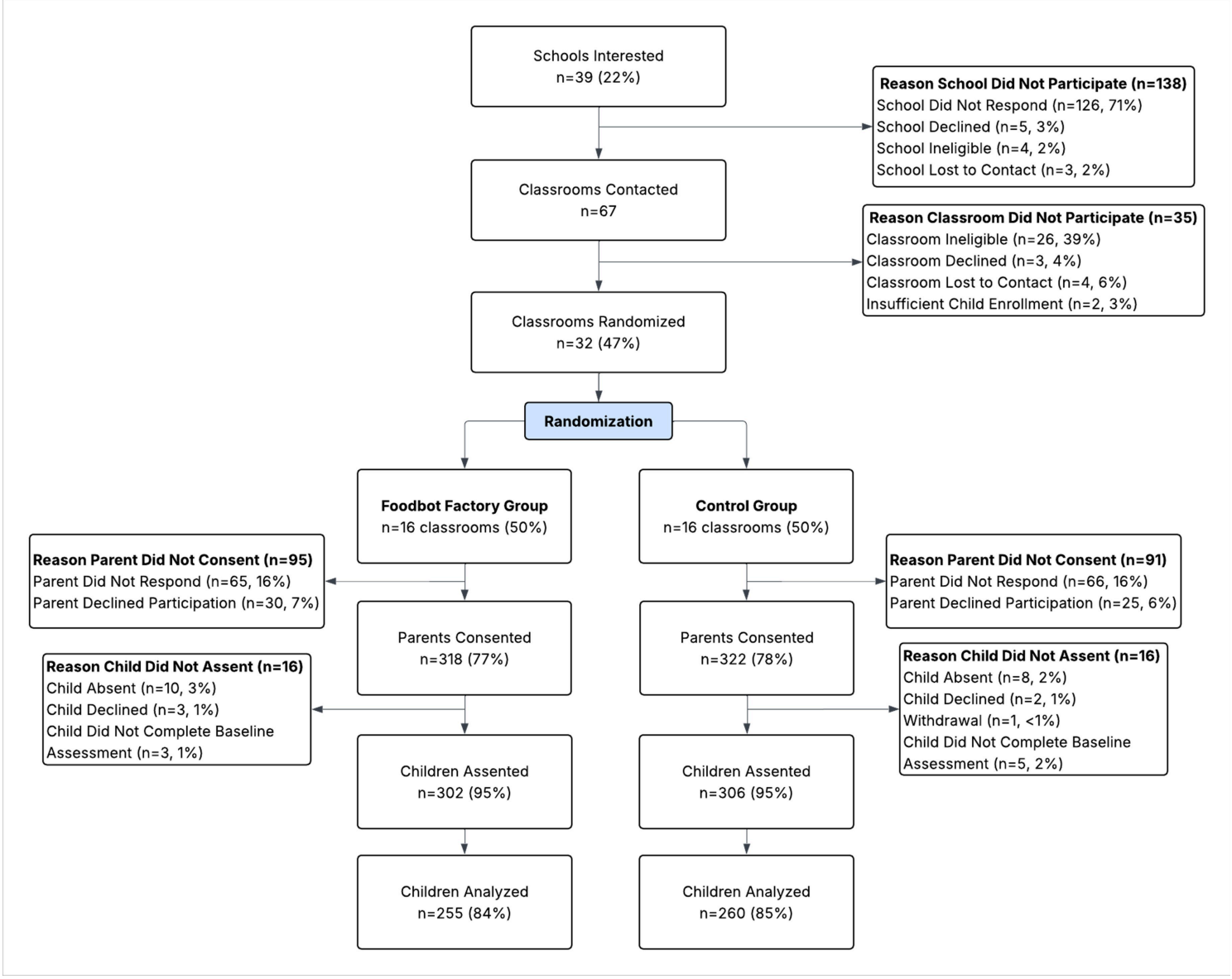

Figure 2

Participant Flow Diagram.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- FFcRCTCONSORTv120260811.doc
- FFcRCTSupplementaryMaterialsv320260720.docx