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Original Article

Designing, Developing and Deploying Smart Nutrition Education Intervention to Promote Nutrition Related Knowledge among School Children: A Cluster Randomized Control Trial

Poulomi Chatterjee[1], Abhay Nirgude[2]*

ABSTRACT

Introduction: School-children undergo rapid growth with high nutritional needs. Adequate nutritional-knowledge promotes healthy eating making nutrition-education essential. This study assessed the impact of a digital platform-based smart nutrition-education intervention on nutritional-knowledge among 10-14-year-old school-children in Mangalore. **Methods:** The study was conducted in five private schools with 596 children equally assigned to intervention and control-clusters (n=298 each). An orientation preceded baseline assessment. Intervention-cluster received a six-month digital program with two educational videos per month on nutrition, diet-planning, physical-activity, lifestyle, and personal-hygiene. Data were collected at baseline, post-intervention and six-month follow-up; control-cluster were assessed at baseline and follow-up. Within-group differences were analyzed using Friedman/Wilcoxon (Bonferroni) test, between-group Mann-Whitney U test with effect sizes Kendall's W and r. Analyses were performed in SPSS 27 ($p<0.05$). **Results:** At baseline, median nutritional-knowledge scores across all topics were similar between intervention and control-clusters with negligible effect-sizes (r) 0.001-0.024 and $p>0.05$. The intervention-cluster showed significant improvements across pre-test, post-test and follow-up ($p<0.001$) with pre-test to post-test (r=0.86-0.89) and pre-test to follow-up (r=0.84-0.89); a small decline from post-test to follow-up (r=0.20-0.62). The control-cluster showed no significant change (r=0.03-0.08, $p>0.05$). At follow-up intervention-cluster scored higher than controls across most topics (r=0.05-0.35, $p<0.05$) except "The food group system and its importance" (r=0.051, p=0.210). **Conclusions:** The digital platform-based intervention significantly improved and sustained nutritional-knowledge among school-children. Its cost-effective, accessible and user-friendly design enables integration into educational systems, adaptation to other health programs and may support therapeutic dietary strategies. Future research should assess its translation into behavioural and health outcomes.

Key words: Child, Health-Education, Internet-Based Intervention, Knowledge, Nutritional-Sciences, Schools

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INTRODUCTION

Malnutrition in Indian children represents a significant public health issue, primarily resulting from insufficient dietary intake. The World Health Organization (WHO) defines malnutrition as a "pathological state resulting from a relative or absolute deficiency or excess of one or more essential nutrients"[1]. Globally, the rates of overweight and obesity, along with the total number of people affected, have risen across all age groups, including both children and adolescents (5 to 19 years) since the year 2000 till now[2]. Children represent the nation's most valuable resource for future development, yet the overall quality of life among school-aged children remains low[3]. The school-age period is marked by a rapid physical and cognitive growth and development[4]. At this stage, the body's need for nutrients is comparatively elevated[5]. Childhood is a period that is dominated by behavioural learning which is an excellent window of opportunity for promoting health. Healthy habits and nutrition related behaviors are established during childhood and track into adulthood. These include food choices, dietary habits, lifestyle and levels of physical activity[6-8]. School going children who possess strong nutrition knowledge are more inclined to adopt healthy eating habits preventing future deficiency disorders and adult onset diseases[9,10]. Hence, educating children about nutrition and highlighting the significance of a balanced diet, different nutrition deficiency disorders and their prevention/management is crucial[11]. Nutrition education has proven to be an effective approach for promoting healthier health related behaviours and it has been previously observed that insufficient knowledge about dietary needs and the nutritional value of different food groups is a major factor contributing to malnutrition in developing countries such as India[12]. Thus, nutrition education can play an important role in this context.

Digital or web-based nutrition education intervention strategies and/ computer tailoring has gained significant popularity in the field of health education over the past decade[13]. Interventions using digital platform are found to be appreciated better, more personally relevant and subjective than general nutrition information[14]. They can use it as per their convenience or time availability and space[15]. Studies have shown that children are more likely to provide accurate information about their food security, diet, and lifestyle behaviours through a digital platform as it is found to be more comfortable in answering some particular type of questions which reduces the embarrassment that one person may feel while answering directly[16]. Online strategies can provide

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a more affordable, accessible and time-saving method for delivering health-related messages[17,18]. Being more effective than general health and nutrition approaches along with the ability to reach a wider audience, web-based nutrition education intervention strategies acts as a promising tool[15].

School going children may have minimum knowledge regarding healthy eating behaviours and nutrition related knowledge[19]. Use of the Internet, digital platform or web based strategies can be a new approach to tackle the issue of inadequate nutritional-knowledge among school children and also can offer a great chance to involve students using interactive multimedia programs[20-22]. Currently, schools in India give little importance to health education or using nutrition knowledge in practice[23]. Since many lifelong healthy or unhealthy habits start in childhood, it is essential to examine nutrition-knowledge among school children[6-8]. Earlier research on the health and nutrition knowledge of Asian Indian children did not evaluate their understanding related to nutrition, diet, personal hygiene, lifestyle and physical activity as a whole[24-26].

Therefore, in order to improve the nutrition related knowledge regarding common nutritional deficiency disorders, balanced diet planning, healthy eating practices, food preferences, lifestyle, physical activity and personal hygiene among largest possible number of school going children and to control the trend of nutrition deficiency disorders, the main objective of the present study is to design a digital nutrition education intervention for school children, and to evaluate the impact of the digital intervention to improve nutrition related knowledge at pre-test, post-test and follow-up among school children in Mangalore, Karnataka, India. Based on this objective, the study hypothesizes that children's knowledge scores will significantly increase from pre-test to post-test and maintain higher levels at follow-up, indicating both immediate and sustained learning.

If the impact of this model can be established, it can give directions in policy making and for future web-based nutritional intervention programmes for schools, educational institutions, health facilities, and the community at a broader level. It may also guide the pharmaceuticals in designing targeted nutraceuticals and integrated nutrition-pharmacotherapy approaches to address nutrient deficiencies, undernutrition, obesity, and adult-onset conditions such as diabetes and cardiovascular diseases, while supporting preventive healthcare strategies grounded in evidence-based nutrition, thereby complementing clinical therapies and enhancing overall public health.

MATERIALS AND METHODS

Research design, study setting and population

A cluster randomized controlled trial was conducted to assess the effect of a digital platform based nutrition education intervention program, comparing intervention and control school clusters (Figure 1). This digital platform-based smart nutrition education intervention study was carried out with students in five private schools in Mangalore, Karnataka, India, ranging in age from 10 to 14 years. Prior to the implementation of this smart intervention program, an orientation session was held in the selected schools to inform participants about the objectives of the intervention and to provide instructions on the effective use of the digital platform. This Nutrition Education Intervention study is called "Smart" because of its digital platform based structured, targeted and effective design empowering school children to make informed healthy choices aiming not just at awareness but effective food related behaviour change.

Sample size

Based on the previous study,[5] to assess the outcome of a nutrition education intervention using digital platform regarding knowledge

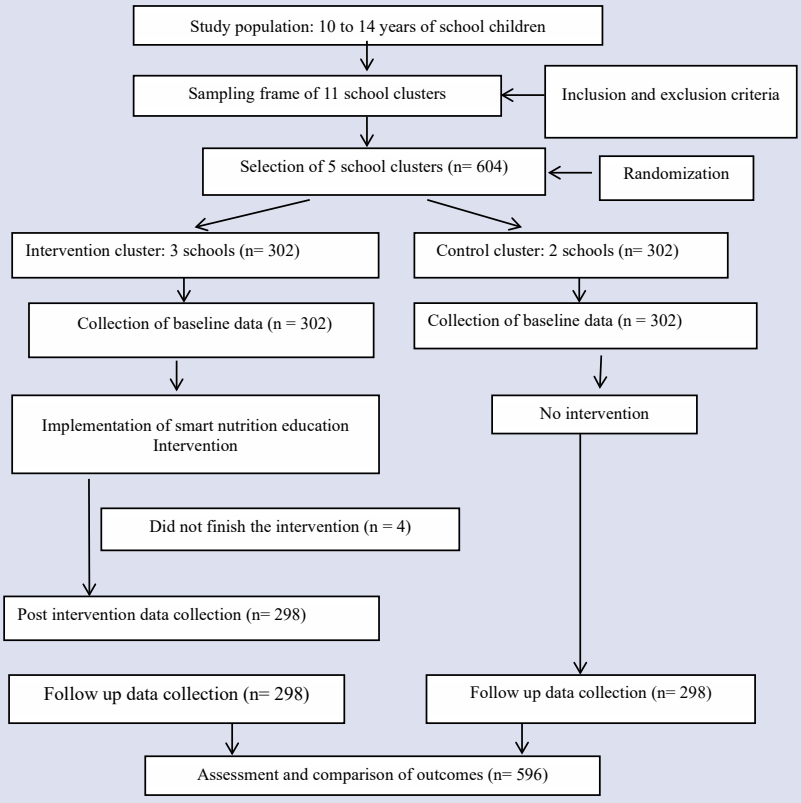

Figure 1. Research design

related to nutrition, among school children, aged 10 to 14 years, in Mangalore, Karnataka, the sample size was calculated. A ratio of 1:1 between intervention and control school clusters was considered for sample size calculation. The total number of participants was estimated as 252 (in each school clusters, intervention and control) having a total sample of 504. After adding 20% non-response error rate the total sample size calculated was 302 in each school cluster, having a total sample size of 604 with a 1% level of significance at 90% power and design effect of 2. At the end of the study, total 596 (298 in each school cluster) school children participated.

Sampling technique

In the first phase, a sampling frame (list) of 11 schools was prepared. Based on inclusion and exclusion criteria 5 schools that met the criteria and consented to participate were included for the study. In the second phase, by using simple random technique, 3 schools were allocated to intervention and 2 schools in control school cluster.

Sampling criteria

- **Inclusion criteria:** School children aged 10 to 14 years were included in the study because dietary habits and food preferences are established in childhood and are closely associated with behaviour and lifestyle. In this phase of life growth spurt remains at its peak and also different nutrient deficiency disorders occur. Following were the requirements for inclusion:

i. Authorization by the school principal to conduct the study

ii. Children aged between 10 to 14 years

iii. Studying in the selected schools

- **Exclusion criteria**: Children who will be absent during two repeated sessions during the intervention were excluded from the study.

Data collection and management

The participants were provided with a complete explanation of the study. Written consent and assent were obtained from parents and the study participants respectively from both the school clusters. They were briefed regarding their involvement which was entirely optional and that they could leave from study and session at any moment with facing no consequences. Here, Pre-test and post-test method was used to impart nutrition education intervention through a digital platform among school children from intervention school cluster. Immediately after the intervention post-test data were collected. Follow-up data was collected after six months of the intervention. Reminders were given and discussions were also conducted through a dedicated WhatsApp group during the intervention. The information regarding socio-demographic characteristics for both the school clusters, and the pre-test and follow-up data for control school cluster was collected through a structured validated questionnaire. Control school clusters received only the standard nutritional guidelines for Indians by National Institute of Nutrition (NIN), ICMR, Hyderabad in the form of digital pamphlets. Each participant was assigned a unique identification code to ensure anonymity. All data were securely stored: hard copies were kept in a locked cabinet, while electronic files were stored on a password-protected computer accessible only to the research team.

Designing and developing the Smart Nutrition Education Intervention module:

The content of nutrition education intervention was designed with reference to the NIN (National Institute of Nutrition) guidelines. The videos were developed and validated by seven subject experts. Repetitive modifications were done to generate the final module. A total of eleven videos covering different nutrition-related topics were created, each accompanied by five multiple-choice questions. These materials were delivered over a six-month intervention period. The nutrition education videos were not longer than 40 minutes. The topics included were concept of nutrients (topic 1), concept of protein and fat (topic 2), role of vitamin-c and zinc (Zn) rich foods in human body (topic 3), different roles of food in human body (topic 4), the food group system and its importance (topic 5), how to plan a balanced diet? (topic 6), importance of nuts and fibre rich foods in the daily diet (topic 7), physical activity and lifestyle- the pillars of fitness (topic 8), personal hygiene-an essential component of healthy life (topic 9), most common nutritional problems in school children (topic 10) and packaged and empty calorie foods vs. Home-made foods and healthy snacking (topic 11).

These topics were selected for the Smart Nutrition Education Intervention module because these are age-appropriate, comprehensive and action-oriented. They were designed to increase nutrition related knowledge about essential nutrition concepts, to encourage healthy behaviours like good personal hygiene and exercise and prevent common health related issues by promoting practical dietary habits.

Developing the Digital Platform and Deploying the Smart Nutrition Education Intervention: A Critical Analysis

The digital platform was designed and developed with the help of the Institutional Technology Incubator Centre. The Smart Nutrition Education Intervention was developed as a digital platform integrating several pedagogical and behavioural components designed to enhance nutritional knowledge. The platform employed a structured sequence: (i) a pre-test containing nutrition-related questions, (ii) an educational video, and (iii) a post-test followed by a six-month follow-up assessment. To ensure compliance, the post-test was only activated once the video had been fully viewed, and participants were given specified time limits to answer each question. Additional features included user authentication and authorization, an administrative dashboard to manage tests and user accounts, upload of resource materials, participant profiles, and secure monitoring of engagement. Participant engagement with the digital platform was tracked by monitoring login frequency, time spent on each module, and completion of all steps through to submission. Adherence was measured based on the completion rates of the visual aids. These measures provide a transparent account of participant interaction with the intervention, enhancing the rigor of the study. The platform link was shared through a dedicated WhatsApp group, and participants were supported and guided throughout the intervention period. Here, the Figure 2 shows the steps for conducting the data collection through the digital platform.

Alignment with Educational Theories

The design incorporated several principles from established educational frameworks. The pre-test served to activate prior knowledge, consistent with Constructivist theory and Kolb's experiential learning cycle, where learners engage in recall before new material is introduced[27,28]. The structured video module, combining visual and verbal channels, aligns with Mayer's Cognitive Theory of Multimedia Learning, which emphasizes dual-channel processing and contiguity of learning materials to enhance knowledge retention[29]. The time-limited post-test functioned as a reinforcement mechanism, reflecting Cognitive Load Theory, by ensuring focused engagement while preventing extraneous distractions[30]. Collectively, this sequence supported active learning, reflection, and knowledge consolidation.

Application of Behaviour Change Models

From a behavioural perspective, the intervention operationalized constructs from multiple models. The Social Cognitive Theory

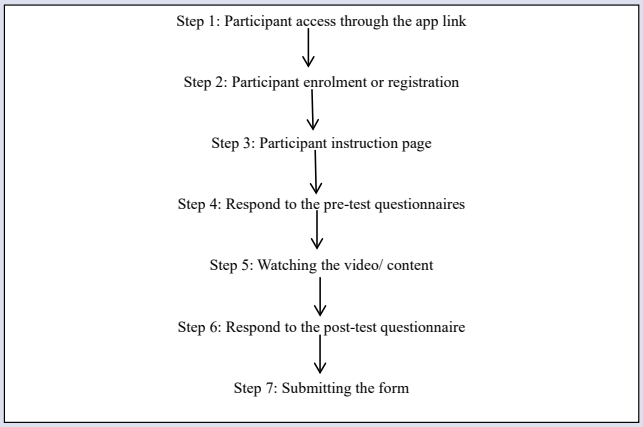

Figure 2. Steps of data collection through digital platform

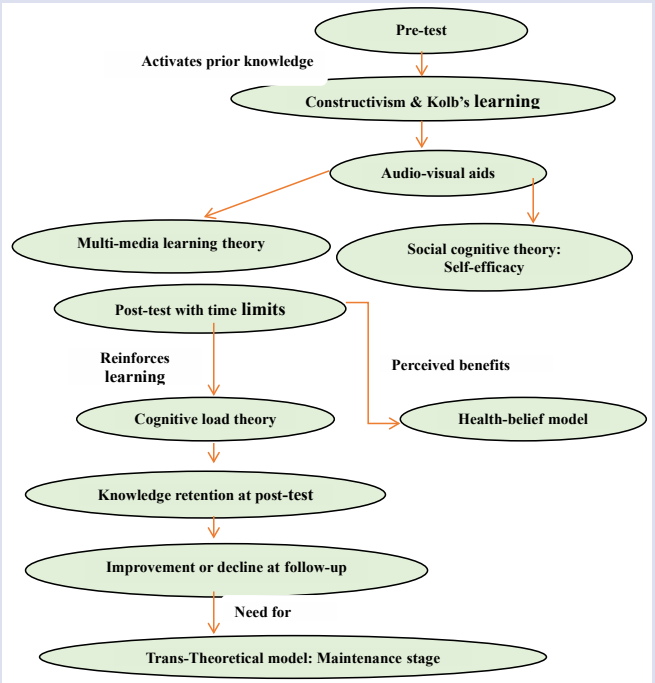

Figure 3. Flowchart of Linking intervention features to theories

(SCT) is reflected in the compulsory video completion and feedback mechanisms, which strengthened learner self-efficacy and confidence in knowledge acquisition[31]. The use of WhatsApp as a delivery channel along with ongoing reminders and discussion, also introduced a social reinforcement component which helped to address the constructs of cues to action. Similarly, the intervention addressed the Health Belief Model (HBM) by increasing perceived benefits of nutrition education through structured interactive learning[32]. Finally, the Trans-Theoretical Model (TTM) provides insight into the improvement or decline in knowledge retention observed at the end of the intervention. The intervention facilitated movement from pre-contemplation to preparation through knowledge acquisition, and also provided reinforcement mechanisms like reminders to support progression to the maintenance stage[33]. The following flowchart in Figure 3, illustrates how the design elements of the digital nutrition education platform align with established educational theories and behaviour change models.

Ethics statement

The approval for conducting the study was obtained from the Institutional Ethics Committee. Formal permission was obtained from the regulatory body, i.e., Block Education Officer (BEO) and school authorities prior to the study. The researcher approached the study participants and explained the study's purpose, benefits and risks. Assent and informed consent were obtained from the participants and their parents, ensuring privacy and confidentiality. The participants were offered the choice to withdraw from the study at any point without any impact on their health care. The National ethical guidelines for biomedical and health research guidelines were strictly followed throughout the study.

Statistical Analysis

All continuous variables were first assessed for normality using the Shapiro-Wilk test. As the nutrition knowledge scores were non-normally distributed, non-parametric tests were employed. For within-group comparisons across three time points (pre-test, post-test, and follow-up) in the intervention cluster, the Friedman test was used to assess changes in knowledge scores. Post-hoc pairwise comparisons were conducted using Wilcoxon signed-rank tests with Bonferroni correction to identify significant differences between specific time points (pre vs post, post vs follow-up, and pre vs follow-up). Effect sizes (W) for repeated measures were calculated using Kendall's W, interpreted according to Cohen's benchmarks (0.1=small, 0.3=moderate, 0.5= large). For between-group comparisons at follow-up (intervention vs control), the Mann-Whitney U test was employed. Absolute values of effect size (r) were used to interpret the magnitude of effects, with 0.1=small, 0.3=medium, and 0.5=large. Descriptive statistics are presented as median and interquartile range (IQR). Data were organized in MS Excel and analyzed on SPSS 27 version. $p<0.05$ was taken as statistically significant. The main outcome variable was improvement in nutrition related knowledge scores of the study participants. Children with incomplete responses or missing data were excluded from the analysis.

RESULTS

Participant characteristics

The socio-demographic characteristics of the study participants have been presented in Table 1. The age variable was not normally distributed based on the Shapiro-Wilk test. Hence, median and interquartile range (IQR) were used. The median age of participants in the intervention school cluster was 11.67 (1.50) years, while that of the control school cluster was 11.33 (1.59) years. Most of the participants in the intervention (93.3%) and control school cluster (92.3%) were between 10-12 years. Majority of the participants in the intervention school cluster (56.7%) were predominantly female, whereas majority of the participants in the control school cluster (51%) were male. The predominant religion was Hinduism in both intervention (57.4%) and control school cluster (66.8%). Most of the participants' head of the family in both intervention (61.1%) and control school cluster (47%) had secondary educational status. Most of the participants' head of the family in both intervention (48%) and control school cluster (44.6%) were skilled workers, shop or market sales workers. Majority of the households of the participants from both intervention (77.2%) and control school cluster (64.8%), had a monthly income of ≤ 25,000 (in rupees).

No significant differences were observed between the study clusters ($p>0.05$) in socio-demographic characteristics like age, gender, family

Table 1. Distribution of study participants according to the socio-demographic characteristics

Sl. No.	Socio-demographic variables	Study clusters f (%)		Statistical value	
		Intervention	Control	χ^2	p
1	**Age in years**			0.23	0.635
	a. 10 - 12	278 (93.3)	275 (92.3)		
	b. 13 - 14	20 (6.7)	23 (7.7)		
2	**Gender**			3.56	0.059
	a. Boys	129 (43.3)	152 (51)		
	b. Girls	169 (56.7)	146 (49)		
3	**Family type**			4.76	0.093
	a. Nuclear	204 (68.5)	210 (70.5)		
	b. Joint/Extended	82 (27.5)	66 (22.1)		
	c. Three generation	12 (4)	22 (7.4)		
4	**Religion**			35.59#	<0.001**
	a. Hindu	171 (57.4)	199 (66.8)		
	b. Muslim	71 (23.8)	20 (6.7)		
	c. Christian	56 (18.8)	78 (26.2)		
	d. Jain	0	1 (0.3)		
5	**Educational status of the head of the family**			51.17	<0.001**
	a. Degree or above	41 (13.8)	86 (28.9)		
	b. Diploma	29 (9.7)	59 (19.8)		
	c. Secondary education	182 (61.1)	140 (47)		
	d. Primary education	41 (13.8)	13 (4.4)		
	e. No formal education	5 (1.7)	0		
6	**Occupational status of the head of the family**			34.43	<0.001**
	a. Legislators/Senior Officials/Managers	3 (1)	19 (6.4)		
	b. Professionals	13 (4.4)	35 (11.7)		
	c. Technicians and Associate Professionals	30 (10.1)	29 (9.7)		
	d. Clerks	25 (8.4)	24 (8.1)		
	e. Skilled/Shop/Market workers	143 (48)	133 (44.6)		
	f. Skilled Agricultural and Fishery Workers	14 (4.7)	16 (5.4)		
	g. Craft/trade workers	14 (4.7)	13 (4.4)		
	h. Plant/Machine Operators	14 (4.7)	7 (2.3)		
	i. Elementary Occupation	42 (14.1)	20 (6.7)		
	j. Unemployed	0	2 (0.7)		
7	**Total monthly income of the family (in rupees)**			5.72	0.057
	a. ≤ 25,000	222 (74.5)	193 (64.8)		
	b. 25,001 – 50,000	61 (20.5)	80 (26.8)		
	c. ≥ 50,001	18 (6.0)	25 (8.4)		

Data presentation: frequency (f) and percentage in parenthesis (%). Abbreviation used: χ^2= chi-square test-statistic; Level of significance: *p<0.0 5 significant; **p<0.01 highly significant; ***p<0.001 very highly significant; p>0.05 non-significant. Study groups: Intervention school cluster (n=298), Control school cluster (n=298).

Table 2. Intergroup comparison of pre-test scores of nutrition related knowledge between intervention and control clusters

Topics	Study groups		Statistical value		
	Intervention (n = 298) Median (IQR)	Control (n =298) Median (IQR)	U	p	r
Topic 1	6 (1)	6 (1)	-0.056	0.955	-0.002
Topic 2	6 (1)	6 (1)	-0.178	0.858	-0.007
Topic 3	6 (1)	6 (1)	-0.117	0.907	-0.005
Topic 4	7 (1)	7 (1)	-0.19	0.85	-0.008
Topic 5	7 (2)	7 (2)	-0.108	0.914	-0.004
Topic 6	6 (1)	6 (1)	-0.182	0.855	-0.007
Topic 7	7 (2)	7 (2)	-0.307	0.759	-0.013
Topic 8	7 (1)	7 (1)	-0.201	0.84	-0.008
Topic 9	5 (1)	5 (1)	-0.586	0.558	-0.024
Topic 10	6 (1)	6 (1)	-0.144	0.885	-0.006
Topic 11	7 (1)	7 (1)	-0.032	0.974	-0.001

Abbreviation used: IQR=Interquartile Range; U=Mann Whitney U test statistic; r = Effect size. Data presentation: Data presented as median (IQR) because distribution was non-normal. Statistical Analysis: The Mann-Whitney U test was used to compare topic wise pre-test nutritional related knowledge scores between the intervention and control groups. Level of significance: *p<0.0 5 significant; **p<0.01 highly significant; ***p<0.001 very highly significant; p>0.05 non-significant.

type, total monthly income of the family indicating that the study clusters were homogenous across these socio-demographic characteristics. However, although significant differences were observed in religion, educational status and occupational status of the head of the family ($p<0.05$), the frequency distributions indicate that the overall patterns across school clusters were largely comparable across these socio-demographic characteristics.

Comparison of pre-test scores of nutrition related knowledge between the intervention and control school clusters

Comparing intervention and control clusters at baseline (Table 2) indicated no significant differences across all the eleven topics ($p>0.05$). Effect sizes were negligible (r=0.001-0.024), indicating comparable baseline status in terms of nutrition related knowledge between clusters.

Comparison of pre-test, post-test and follow-up scores of nutrition related knowledge within the intervention and control school clusters

Table 3 shows significant changes in nutrition knowledge across the three time points (pre-test, post-test and follow-up) for all topics (χ^2=494.23-560.68, p 0.001) within the intervention school cluster. Effect sizes (Kendall's W) ranged from 0.83 to 0.94 indicating very large effects of the digital nutrition education intervention. The largest effects were observed for "The food group system and its importance" (W=0.94) and "How to plan a balanced diet" (W=0.93), suggesting these areas benefited most from the program. Topics with slightly lower effect sizes, such as "Concept of nutrients" and "Packaged vs home-made foods" (W=0.83) also demonstrated substantial improvements, confirming the overall effectiveness of the intervention in enhancing nutrition-related knowledge among school children.

Table 4 presents the intragroup pairwise comparisons of nutrition related knowledge scores within the intervention cluster, indicating statistically significant improvements across all topics from pre-test to post-test, pre-test to follow-up, and post-test to follow-up ($p<0.001$ after Bonferroni correction). Significant improvements were reported in nutrition knowledge from pre to post-intervention across all topics with very large effect sizes (r=0.86-0.89). While some reduction in scores was observed between post-test and follow-up (small to moderate effect sizes, r=0.20-0.62) and overall knowledge retention at follow-up remained substantially higher than baseline (r=0.84-0.89). However, the largest sustained retention was noted for personal hygiene (r=0.62), while the smallest was for packaged versus home-made foods (r=0.20). The findings indicate that the nutrition education intervention was impactful in enhancing nutrition related knowledge.

In contrast, control school cluster showed no significant difference ($p>0.05$) in topic-wise comparisons of nutrition related knowledge between pre-test and follow-up across any of the assessed topics (Table 5). Effect sizes were negligible (r=0.03-0.08), suggesting stability in knowledge over time rather than further gains or losses. This indicates that, in the absence of the intervention, the nutrition knowledge of the participants remained unchanged over time.

Comparison of follow-up scores of nutrition related knowledge between the intervention and control school clusters

A significant improvement ($p<0.05$) was observed in nutrition related knowledge scores at follow-up in intervention school cluster compared to control cluster (Table 6) across most topics, except for the topic 'the food group system and its importance' (p=0.210). Effect sizes for the intervention compared to control cluster ranged from small to moderate (r=0.05-0.35). The largest effects were observed for the topics on personal hygiene (r=0.35) and most common nutritional problems (r=0.24), indicating that the intervention had the greatest impact on these areas, while other topics showed relatively smaller but significant improvements compared to the control school cluster.

DISCUSSION

This smart nutrition education intervention program, delivered through a digital platform was designed and developed to provide a comprehensive, cost-effective, accessible and time efficient approach to nutrition education. It aimed to enhance nutrition related knowledge of the school children about food, dietary habits, lifestyle, physical activity and personal hygiene directly benefiting the participants of the study. The present study assessed the impact of a digital platform-based nutrition education intervention in enhancing nutrition related knowledge among school children aged 10-14 years, in contrast to conventional classroom teaching. Early to middle adolescence represents a critical period for the development of behavioural patterns that can influence long-term health and well-being[34].

The participants in this study were predominantly aged 10-12 years, a developmental stage when children begin to form lasting health

Table 3. Intragroup comparison of nutrition related knowledge scores within the intervention school cluster (n = 298)

Topics	Pre-test	Post-test	Follow-up	Statistical value		
	Median (IQR)	Median (IQR)	Median (IQR)	χ^2	p	W
Topic 1	6 (1)	8 (1)	7 (1)	494.23	<0.001***	0.83
Topic 2	6 (1)	9 (1)	6 (1)	550.50	<0.001***	0.92
Topic 3	6 (1)	9 (1)	7 (1)	546.69	<0.001***	0.92
Topic 4	7 (1)	9 (1)	7 (2)	555.50	<0.001***	0.93
Topic 5	7 (2)	10 (0)	7 (2)	560.68	<0.001***	0.94
Topic 6	6 (1)	10 (0)	7 (1)	554.09	<0.001***	0.93
Topic 7	7 (2)	10 (0)	7 (1)	552.48	<0.001***	0.93
Topic 8	7 (1)	10 (0)	7 (2)	548.52	<0.001***	0.92
Topic 9	5 (1)	9 (0)	6 (0)	549.60	<0.001***	0.92
Topic 10	6 (1)	9 (0)	7 (1)	537.50	<0.001***	0.90
Topic 11	7 (1)	10 (0)	6 (1)	494.69	<0.001***	0.83

Abbreviation used: IQR=Interquartile Range; χ^2=Friedman test statistic; W = Kendall's W. Data presentation: Data presented as median (IQR) because distribution was non-normal. Statistical analysis: The Friedman test was used to compare the topic wise nutrition related knowledge scores across three time points within the intervention group. Level of significance: *p<0.0 5significant; **p<0.01 highly significant; ***p<0.001 very highly significant; p>0.05 non-significant.

Table 4. Intragroup pairwise comparison of nutrition related knowledge scores within the intervention school cluster (n = 298)

Topics	Pre-test vs Post-test			Post-test vs Follow-up			Pre-test vs Follow-up		
	W	p	r	W	p	r	W	p	r
Topic 1	-14.779	<0.001***	-0.856	-9.707	<0.001***	-0.562	-14.480	<0.001***	-0.839
Topic 2	-15.152	<0.001***	-0.878	-5.420	<0.001***	-0.314	-14.978	<0.001***	-0.868
Topic 3	-15.041	<0.001***	-0.871	-8.128	<0.001***	-0.471	-14.957	<0.001***	-0.866
Topic 4	-14.935	<0.001***	-0.865	-6.410	<0.001***	-0.371	-14.936	<0.001***	-0.865
Topic 5	-14.890	<0.001***	-0.863	-5.324	<0.001***	-0.308	-14.902	<0.001***	-0.863
Topic 6	-15.016	<0.001***	-0.870	-7.469	<0.001***	-0.433	-15.017	<0.001***	-0.870
Topic 7	-15.046	<0.001***	-0.872	-7.884	<0.001***	-0.457	-15.126	<0.001***	-0.876
Topic 8	-15.001	<0.001***	-0.869	-7.627	<0.001***	-0.442	-15.017	<0.001***	-0.870
Topic 9	-15.344	<0.001***	-0.889	-10.734	<0.001***	-0.622	-15.274	<0.001***	-0.885
Topic 10	-15.127	<0.001***	-0.876	-9.766	<0.001***	-0.566	-15.070	<0.001***	-0.873
Topic 11	-15.114	<0.001***	-0.876	-3.393	<0.001***	-0.197	-15.037	<0.001***	-0.871

Abbreviations used: W = Wilcoxon Signed-Rank Test statistic; r = Effect size. Data presentation: Data compared between time points within the intervention group using Wilcoxon Signed-Rank Test. Statistical analysis: Bonferroni correction applied to account for multiple comparisons (adjusted significance threshold = 0.05/3 = 0.0167). Level of significance: *p<0.0167 significant; **p<0.01 highly significant; ***p<0.001 very highly significant; p>0.05 non-significant.

Table 5. Intragroup comparison of nutrition related knowledge scores within the control school cluster (n = 298)

Topics	Pre-test	Follow-up	Statistical value		
	Median (IQR)	Median (IQR)	W	p	r
Topic 1	6 (1)	6 (1)	-0.775	0.439	-0.045
Topic 2	6 (1)	6 (1)	-0.447	0.655	-0.026
Topic 3	6 (1)	6 (1)	-0.853	0.394	-0.049
Topic 4	7 (1)	7 (1)	-0.632	0.527	-0.037
Topic 5	7 (2)	7 (2)	-0.688	0.491	-0.040
Topic 6	6 (1)	6 (1)	-0.894	0.371	-0.052
Topic 7	7 (2)	7 (2)	-0.707	0.480	-0.041
Topic 8	7 (1)	7 (1)	-0.816	0.414	-0.047
Topic 9	5 (1)	5 (1)	-1.134	0.257	-0.066
Topic 10	6 (1)	6 (1)	-1.414	0.157	-0.082
Topic 11	7 (1)	7 (1)	-1.000	0.317	-0.058

Abbreviations used: IQR = Interquartile Range; W = Wilcoxon signed-rank test statistic; r = Effect size. Data presentation: Data are presented as median (IQR) because the distribution was non-normal. Statistical analysis: The Wilcoxon signed-rank test was used to compare pre-test and follow-up topic wise nutrition related knowledge scores within the control group. Level of significance: *p<0.05 significant; **p<0.01 highly significant; ***p<0.001 very highly significant; p>0.05 non-significant.

Table 6. Intergroup comparison of follow-up nutrition related knowledge scores based on topics between the intervention and control school cluster (n = 596)

Topics	Follow-up scores		Statistical value		
	Intervention (n = 298)	Control (n = 298)	U	p	r
	Median (IQR)	Median (IQR)			
Topic 1	7 (1)	6 (1)	-4.575	<0.001***	-0.187
Topic 2	6 (1)	6 (1)	-2.504	0.012*	-0.102
Topic 3	7 (1)	6 (1)	-3.290	0.001***	-0.135
Topic 4	7 (2)	7 (1)	-1.991	0.046*	-0.082
Topic 5	7 (2)	7 (2)	-1.254	0.210	-0.051
Topic 6	7 (1)	6 (1)	-3.053	0.002**	-0.125
Topic 7	7 (1)	7 (2)	-3.764	0.001***	-0.154
Topic 8	7 (2)	7 (1)	-3.519	0.001***	-0.144
Topic 9	6 (0)	5 (1)	-8.467	0.001***	-0.347
Topic 10	7 (1)	6 (1)	-5.829	0.001***	-0.239
Topic 11	6 (1)	7 (1)	-2.186	0.029*	-0.090

Abbreviations used: IQR = Interquartile Range; U = Mann–Whitney U test statistic. Data presentation: Data presented as median (IQR) because distribution was non-normal. Statistical analysis: The Mann–Whitney U test was used to compare follow-up topic wise nutrition related knowledge score between the intervention and control groups. Level of significance: *p<0.0 5significant; **p<0.01 highly significant; ***p<0.001 very highly significant; p>0.05 non-significant.

behaviours and are receptive to structured learning interventions[35]. Socio-demographic characteristics revealed that most participants' heads of household had secondary education and were employed as skilled workers or shop/market sales workers, while the majority of households reported a monthly income ≤ ₹25,000. These findings reflect a moderately educated but economically constrained population, consistent with school based nutrition intervention studies in low and middle income contexts[36,37]. Parental education and household income are known to influence both baseline knowledge and the capacity to translate educational gains into practice[38,39]. Parents with a high socio-economic status are generally more educated, have higher-quality jobs, and are more inclined to use social and financial resources to provide their children with educational benefits[40]. The predominance of Hinduism across the clusters minimized religious variability, indicating that cultural influences on nutritional knowledge were relatively uniform, consistent with findings reported in previous studies[41,42].

At baseline, there was no significant differences observed in nutrition related knowledge score between the intervention and control clusters ($p>0.05$). This comparability is important, as it establishes a fair starting point and strengthens the internal validity of subsequent group differences. The finding is consistent with prior cluster-based school intervention studies where demographic homogeneity minimized baseline disparities[43,44].

Following the intervention, significant improvements in the intervention cluster was reported across pre-test, post-test, and follow-up ($p<0.001$). Pairwise comparisons confirmed significant gains from pre-test to post-test and pre-test to follow-up ($p<0.001$), with a significant decline between post-test and follow-up ($p<0.001$) although follow-up scores remained higher than baseline, suggesting knowledge retention over time. In contrast, the control cluster showed no significant change between pre-test and follow-up ($p>0.05$). Furthermore, between-cluster comparisons demonstrated that the intervention cluster had significantly higher knowledge score at follow-up than the control cluster ($p<0.001$) with small to moderate effect sizes across most of the topics. These findings are consistent with a digital intervention study which reported significant but modest improvements in the nutritional knowledge among children compared to controls[45]. Review studies on the effectiveness of a digital nutrition education program among school children also indicated that children who participated in the digital intervention showed significant improvements in nutrition knowledge compared to those who received traditional classroom-based education or no education[46,47]. The largest effect sizes were observed for the topics on personal hygiene ($r=0.35$) and most common nutritional problems ($r=0.24$) which contribute to the growing body of evidence indicating an increase from 53.8% to 87.5% in understanding general body cleanliness practices and common nutritional issues, leading to better dietary choices and health outcomes[48,49]. These studies underscore the importance of integrating personal hygiene and common nutritional problems into school nutrition education programs, as they are areas where students demonstrate significant knowledge gains.

However, no significant difference was observed for one topic "the food group system and its importance" ($p=0.210$). Similar challenges have been reported in other nutrition education programs, where more abstract or conceptual topics are harder for children to grasp and retain compared to applied, behaviour-linked content[37,50]. This highlights the need for more interactive, gamified or contextually tailored strategies for abstract nutrition concepts.

Nutrition is included in school primers to some degree, but video sessions like ours make evidence more engaging for students and provide rational guidelines for adopting healthy nutrition practices. Previous studies have also highlighted that the first step towards changing nutrition related behaviour is to provide personally relevant, cost-effective, accessible, time-efficient and more subjective of learning for enhancing nutrition related knowledge[14,17]. School children lack the innate ability to select a nutritious diet[51]. As a result, it is crucial to train them about health and nutrition while they are still in school. As reported in previous studies concepts like energy, proteins, carbohydrates, and saturated fats were unknown to the kids[52,53]. They also lacked an understanding of nutritive value and how combining cereals and pulses could enhance the nutritional content of food. This gap in knowledge on dietary substances can help to explain excessive consumption of fatty foods and the resulting enhanced rates of obesity among school children[54]. Children and their parents often lack awareness of credible information sources, exposes them to the risk of making poor food related decisions[55]. Previous research has also indicated that a child's understanding of nutrition is predominantly shaped by their home and school environment[56]. Accurate nutrition information is particularly important for school-aged children, as they can share this knowledge with their families and communities, helping to adjust food preparation strategy and incorporate healthier food options[57]. A study conducted by 2019 Nobel Prize winners in Economics, it was observed that in India, individuals living in poverty do not prioritize spending their limited financial resources on healthy food[58]. The analysis also emphasized that, even within the lowest income brackets, approximately 50% of any 1% increase in food expenditure is allocated towards purchasing extra calories, while the other half is spent on more expensive, calorie-dense foods that are likely to be tastier[59]. School-aged children can bridge the disconnection among theoretical knowledge and practical application by comprehending significance of eating wholesome nutritious diet[60].

Digital platform-based nutrition and health education can offer substantial benefits for health systems by enabling both professionals and consumers including children and youth to acquire evidence-based knowledge and potentially may adopt healthier behaviours. Systematic reviews have shown that interventions using audio-visual aids and interactive content are effective for improving nutrition knowledge which have the potential to improve dietary practices[61,62]. With few words and lots of images to convey the message, it is portable, reusable, and holds the audience's interest. To meet local needs, the information can be readily modified. Children can learn about nutrition with this method, and as a result, visual messages are easier to comprehend and retain[63,64]. This approach could be readily implemented to enhance people's knowledge and practices at the primary health care level. At the PHC level, ANMs and ASHA employees can receive training on how to conduct community meetings using these audio-visual aids and standardize the main points that are communicated by these various health worker cadres.

The findings of this study indicate that informal and digital nutrition education sessions can effectively enhance school-age children's nutritional knowledge supporting both immediate learning and long-term retention. By incorporating compulsory video completion, feedback mechanisms, reminders, discussion, and multimodal instructional strategies, the intervention not only improved knowledge scores from pre to post-test but also maintained elevated levels at follow-up. These results highlight the potential of interactive, technology-based approaches to empower children and strengthen the broader healthcare framework in addressing nutrition-related deficiencies. Consistent with previous research, the study underscores the value of engaging, community-inclusive educational programs in promoting nutrition literacy[45]. At the same time, the findings prompt further inquiry into whether increased knowledge translates into behavioural changes, how such interventions perform across different age groups, and their feasibility for scaling within diverse educational and community contexts.

CONCLUSION

The Smart Nutrition Education Intervention, delivered via a digital platform, effectively enhanced and maintained nutritional knowledge among school-aged children, demonstrating the value of technology-based learning in health education. Grounded in constructivist principles, multimedia learning theory, and behavior change models, the intervention combined a strong theoretical foundation with engaging, pedagogically sound design. Features such as pre, post and follow-up assessments, compulsory video completion, limited time frame and administrator oversight promoted active participation, accountability and learning authenticity.

These findings underscore the feasibility and scalability of cost-effective, user-friendly digital tools in school settings, particularly where resources or trained facilitators are limited. The intervention's adaptability also suggests broader applicability beyond nutrition, offering a model for other health promotion and educational initiatives. By leveraging innovative digital strategies, such programs can support widespread dissemination of knowledge and provide a foundation for future studies to examine behavioural and dietary outcomes.

Beyond educational benefits, the results carry important implications for the pharmaceutical and public health sectors. Enhanced nutrition knowledge in children can guide targeted supplementation programs, inform the development of evidence-based nutraceuticals, and support early preventive interventions aimed at reducing the risk of obesity, micronutrient deficiencies, diabetes, and cardiovascular disease later in life. Integrating digital education with nutrition-focused healthcare initiatives may improve adherence to therapeutic regimens and strengthen preventive health strategies, highlighting the potential for synergistic effects between educational interventions and clinical practices. Future research should investigate the translation of improved knowledge into dietary behavior change, long-term health outcomes, and the optimization of digital platforms across diverse populations and settings.

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