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A Study on the Effectiveness of a Health Education Intervention Combining an Online Digital App for HFMD with Offline Health-themed Cultural and Creative Products

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Abstract

Hand-foot-mouth disease (HFMD) is a Class C infectious disease prevalent among infants and toddlers under 5 years old. There are no specific antiviral drugs available for its treatment, making health education a core strategy for prevention and control. To develop a tiered and fully inclusive popular science model for HFMD prevention, this study recruited 318 primary caregivers of young children and 216 kindergarten staff in Wenzhou as research subjects. A self-designed questionnaire covering HFMD awareness and health behaviors was compiled, and two types of publicity carriers—an immersive virtual simulation education APP and daily-use health cultural and creative products—were developed for a 3-month combined intervention. Paired t-tests, chi-square tests and binary logistic regression were adopted to analyze intervention effects. The results indicated that after intervention, the awareness rate of HFMD knowledge among both groups and the compliance rate of healthy behaviors among family caregivers increased significantly ($P < 0.05$). Both the APP and health cultural and creative products acted as independent positive protective factors for improving disease prevention awareness. The online APP suits young and middle-aged populations, while offline cultural and creative products can reach elderly caregivers with low digital literacy; the integration of the two eliminates coverage gaps in health education. This study verifies that the integrated publicity model combining digital online tools and daily cultural and creative products can effectively improve the infectious disease health literacy of populations related to preschool childcare, and provides practical solutions for routine health education in communities and kindergartens.

Keywords: HFMD; Health Education; Virtual Simulation APP; Health-Themed Cultural and Creative Products; Health Literacy; Childcare and Early Years Population

1. Introduction

Hand foot and mouth disease (HFMD) is caused by infection with pathogens of the enterovirus genus. It is a highly prevalent Class C notifiable infectious disease in China, with infants and young children aged five years and under constituting the primary susceptible population; this age group accounts for over 85 % of all cases, and the average age of infection is just 2.3 years. Typical clinical manifestations of the disease include fever and vesicular lesions on the hands, feet and mouth. Whilst most mild cases resolve spontaneously, a small number of children may rapidly progress to severe complications such as aseptic encephalitis, myocarditis and acute flaccid paralysis, posing a short-term risk of death and placing significant pressure on public health prevention and control efforts. In 2008, China formally classified HFMD as a Category C notifiable infectious disease. Between 2008 and 2017, the incidence of this disease consistently ranked first among all Category C infectious diseases nationwide. Cluster outbreaks frequently occur in childcare centres and households; given the high proportion of asymptomatic infections, multiple routes of transmission and rapid spread, the effectiveness of traditional, single-channel offline public education models has been limited.

With regard to the current state of diagnosis and treatment, there are as yet no highly effective, specific antiviral drugs against enteroviruses available globally; clinically, only symptomatic and supportive treatment can be provided. Consequently, interrupting transmission routes and enhancing the health literacy of carers of susceptible populations have become the core strategies for prevention and control, and the value of health education has been confirmed by numerous clinical and public health studies. The National '14th Five-Year Plan for National Economic and Social Development' explicitly sets out the strategic requirements to comprehensively disseminate health knowledge and improve the national health education system. The 'Healthy China Initiative (2019–2030)' further emphasises the routine public science communication regarding key childhood infectious diseases, promoting a shift in health education from mere knowledge dissemination towards innovative models that are integrated into daily life, digitalised and tailored to different levels. Consequently, the innovative development of health education delivery platforms has become a key research focus in the field of public health.

Epidemiological surveillance data show that in May 2022, 519,156 cases of HFMD—a Category C infectious disease—were reported nationwide, with a cumulative death toll of 2,002; the harm to children's health and the economic burden on families caused by this disease continue to be prominent. Zhejiang Province ranks among the top in the country in terms of economic development and residents' health literacy, and boasts a high coverage rate of childcare and early years education facilities, providing favourable conditions for conducting innovative pilot schemes on health education for childhood infectious diseases. Traditional health education has predominantly relied on in-person lectures and leaflets, which suffer from shortcomings such as low audience engagement, difficulties in comprehension among middle-aged and elderly caregivers, and poor retention of fragmented knowledge; digital online science communication faces the challenge of the digital divide among the elderly. Both of these single-channel approaches leave gaps in population coverage.

Whilst some domestic teams have already developed online educational apps for HFMD and organised offline community outreach activities, few studies have combined digital virtual simulation apps with everyday health-themed cultural and creative products to simultaneously implement controlled interventions targeting two core high-risk groups—family caregivers and kindergarten staff—and there is a lack of empirical analysis on the effectiveness of integrated online-offline models.

Based on the aforementioned epidemiological situation, national health strategy requirements, and the shortcomings of existing health education models, this study aims to use a sample of individuals involved in early childhood care and education in Wenzhou, Zhejiang Province, to investigate the intervention effects of integrated health education—combining virtual simulation apps with health-themed cultural and creative products—on the level of knowledge regarding HFMD and the adoption of healthy behaviours. The study also aims to identify key factors influencing the acquisition of disease prevention knowledge and to develop a stratified, targeted science communication programme tailored to individuals of different ages, educational backgrounds, and caregiving roles.

The specific objectives of this study include: (1) to investigate the current status of basic knowledge regarding HFMD and the implementation of health behaviours among family caregivers and kindergarten staff prior to the intervention, and to analyse baseline differences in knowledge between the two groups; (2) to implement a combined online (APP) and offline (cultural and creative products) intervention, and to compare changes in knowledge retention rates and health behaviour compliance rates for HFMD in both groups before and after the intervention, thereby validating the effectiveness of the intervention model; (3) To validate the independent effects of the two educational delivery methods—the mobile app and cultural and creative products—on improving participants' knowledge through univariate chi-squared tests and multivariate binary logistic regression, and to identify demographic factors influencing the acquisition of disease prevention knowledge; (4) To propose implementation strategies for blended online and offline health education targeting community households and early childhood care and education institutions, based on the differences observed across subgroups, thereby providing practical guidance for the routine prevention and control of childhood infectious diseases.

The theoretical significance of this study lies in: enriching the theoretical framework on innovative delivery methods for health education on childhood infectious diseases, and confirming the synergistic benefits of combined interventions using digital interactive tools and lifestyle-oriented cultural and creative products;distinguishing differences in the reception of health information between family caregivers and kindergarten staff, thereby refining the research framework on determinants of health literacy regarding HFMD; the adapted HFMD-specific cognitive scale, having undergone rigorous reliability and validity testing, can serve as a standardised measurement tool for subsequent regional epidemiological health education studies of a similar nature, and supplement empirical research data on health literacy regarding infectious diseases among childcare populations in China.

2. Current Status of Research at Home and Abroad

2.1. Current Status of Domestic Research

The first case of HFMD in China was reported in Shanghai in 1981, followed by localised outbreaks in multiple provinces and cities across the country. The history of domestic research on HFMD is divided into a low-incidence research period (2005–2007), a rapid rise period (2008–2012) and a steady decline period (2013–2014). Following its classification as a Category C infectious disease in 2008, the volume of relevant literature increased significantly, and research interest has continued to rise. An analysis of national HFMD incidence trends from 2008 to 2017 by Li et al. (2021) confirmed that the disease exhibits a pattern of high incidence every other year, with severe cases and fatalities concentrated among children under three years of age; children under five years of age constitute the highest-risk group, and these epidemiological characteristics have remained stable over the long term (Li et al., 2022).

The four core areas of research on HFMD in China are epidemiological and clinical characteristics, antiviral drug treatment, prevention and control of severe complications, and integrated traditional Chinese and Western medical interventions, with the most extensive findings in the areas of epidemiology and health education. Li et al. (2021), in their analysis of ten years of epidemiological characteristics in Wuwei City, proposed that childcare facilities are the primary sites of outbreaks, and that parents' insufficient awareness of disease prevention is the foremost risk factor for cluster outbreaks; targeted health education involving collaboration between homes and childcare facilities is therefore required (Li et al., 2021). Wu et al. (2020), in their study on the epidemiological characteristics of the dominant Cox A6 strain, pointed out that the new strain is more transmissible, the risk of infection is significantly higher in households with low awareness, and the effectiveness of conventional paper leaflets is limited; there is an urgent need for innovative science communication platforms to improve knowledge retention rates (Wu et al., 2022).

Regarding parents' health education needs, multiple surveys have confirmed that parents of affected children are most concerned about HFMD prevention measures and typical symptoms, whilst their understanding of early recognition of severe cases and viral transmission routes is weak. Traditional one-way lectures cannot meet the diverse knowledge needs of different population groups, and there is a marked stratification in the preferred communication channels among different demographics: middle-aged and elderly carers tend to reject online digital health education, whereas younger parents are more receptive to learning via short videos and interactive online platforms (Yuan et al., 2015). Su et al. (2021) confirmed that standardised clinical care pathways combined with personalised health education can significantly enhance parents' caregiving capabilities; however, this model is only applicable to hospitalised children and cannot cover families with healthy infants and young children in the community, thus presenting limitations in terms of the educational setting (Su et al., 2021).

With regard to digital health education tools, domestic scholars have developed online mini-programmes providing health information on HFMD; however, most products offer only text-based information, lack virtual interactive simulations for childcare settings, and do not provide

accompanying offline materials to bridge the digital divide. Whilst the model of medical student volunteer teams conducting health education in communities and nurseries has been proven feasible, current practices fail to integrate cultural and creative products into routine health education, making it difficult to achieve long-term, subtle knowledge dissemination (Qin et al., 2020). Furthermore, whilst newborns and preterm infants are at high risk of contracting HFMD, mothers' insufficient awareness of disease prevention is a key contributing factor; existing research lacks integrated educational programmes covering carers across all age groups (National Health Commission, 2010).

2.2. Current Status of International Research

Globally, the disease burden of HFMD caused by enteroviruses continues to increase, with temperate and subtropical countries in Asia being high-incidence regions. Meteorological factors such as temperature and humidity are key environmental variables influencing viral transmission, a conclusion that has been validated by cohort studies in multiple countries (Shi et al., 2024). A cohort study of emergency departments in California, USA, demonstrated that a humid, temperate coastal climate prolongs the in vitro survival of enteroviruses; seasonal temperature fluctuations are significantly correlated with the number of HFMD presentations, suggesting the need to implement preventive health education in advance, taking climate conditions into account (Gao, 2021). Epidemiological surveillance in the Mumbai region of India has revealed co-circulation of Coxsackieviruses A6 and A16, with a relatively high proportion of recurrent infections and cases of generalised herpetic rash. Parents' insufficient ability to recognise recurrent cases can lead to delays in diagnosis and treatment. Whilst international research has largely focused on meteorological and pathogen epidemiology, there has been limited research into innovative health education platforms targeting community carers and early childhood education and care staff (Zhang and Liu, 2021).

Digital health education represents a mainstream trend in global public health development. Many countries in Europe and the United States have incorporated digital tools for infectious disease public education into basic community public health services; however, most international online public education products are tailored to their own languages and childcare systems, and are not suited to the specific circumstances in China, where early childhood education and care institutions operate under a collective management model and where infants and young children are often cared for by multiple generations (Huang et al., 2014). Foreign research has confirmed that purely online digital health education suffers from significant shortcomings in terms of population reach; older adults and those with low levels of education show extremely low willingness to use such platforms. Whilst physical health education materials can effectively compensate for gaps in online coverage, no empirical research has yet been conducted abroad on the use of everyday cultural and creative products as long-term educational tools for children regarding infectious diseases (Chen et al., 2014).

Existing domestic and international research has confirmed that health education is a key measure for the prevention and control of HFMD, and that digital health education offers the advantages of efficiency and interactivity; however, both online-only and offline-only approaches suffer from limitations in audience reach. There is a lack of empirical research in China on the

integrated intervention model of 'virtual simulation apps combined with health-themed creative products', and no comparative analysis has been conducted on the effectiveness of interventions for the two core groups: family caregivers and kindergarten staff (Andreoni and Colton, 2017). Current Status of HFMD Research at Home and Abroad There is an urgent need for early prevention and control of HFMD; consequently, integrating digital technology into its prevention and control has emerged as an efficient, innovative and contemporary approach to health education. Building upon existing research gaps, this study develops complementary online and offline educational platforms. Through questionnaire surveys and multidimensional statistical analysis, it validates the value of the intervention, thereby providing empirical support for innovation in health education regarding paediatric infectious diseases in China.

3. Subjects and Methods

3.1. Study Population

This study employed a stratified sampling method, selecting two groups as survey subjects: family caregivers of infants and young children in communities in Wenzhou, Zhejiang Province, and staff at public and private kindergartens. Two rounds of questionnaires were distributed—one before and one after the intervention—with strict inclusion and exclusion criteria established:

3.1.1. Inclusion Criteria

(1) family caregivers: Individuals with infants and young children aged 5 years or under at home, who are primarily responsible for their daily care, who voluntarily participate in the questionnaire survey, and who are able to complete the questionnaire independently; (2) Kindergarten staff: Currently employed kindergarten staff, childcare workers, health and hygiene teachers, and administrative and support staff within kindergartens, who have daily contact with pre-school children, have been in post for ≥3 months, and have given informed consent to participate in the study; (3) Participants must have normal cognitive function, no reading or writing difficulties, and be able to cooperate in completing the pre-survey, the main questionnaire and the post-intervention follow-up; (4) The study area comprises all districts and counties of Wenzhou City, Zhejiang Province, with stratified coverage of urban, suburban and rural communities, as well as early childhood care and education institutions.

3.1.2. Exclusion Criteria

(1) Individuals with mental illness or cognitive impairment who are unable to independently comprehend the questionnaire items; (2) Invalid responses, including those where participants withdrew from the study midway, left sections of the questionnaire blank, provided logically inconsistent answers, or ticked all options uniformly; (3) Individuals providing short-term, temporary care for infants and young children, or those in short-term part-time roles at nursery schools, who lack long-term childcare experience.

3.1.3. Sample Overview

The team obtained information on existing scales through a review of the literature. Drawing on these scales, the survey categories were divided into basic knowledge and perceptions of HFMD; its prevention; its management and treatment; and the identification of pathogens and sources of infection, among others, and scoring criteria were established based on this classification. As of 5 September 2021, a total of 593 questionnaires had been distributed, yielding an overall valid sample of 534 cases. The sample encompassed individuals of different genders, ages, educational backgrounds, occupations and caregiving roles; the demographic distribution closely mirrored the actual social structure of the early childhood education and care population in Wenzhou, Zhejiang Province, and was therefore highly representative. After excluding invalid questionnaires, the valid sample comprised 318 family caregivers; Questionnaires were distributed to kindergarten staff both before and after the intervention; after excluding invalid questionnaires, the valid sample comprised 216 cases.

3.2. Research Methods

3.2.1. Research Tools

This study drew upon the ‘Chinese Residents’ Health Literacy Scale for Infectious Diseases’ (Hu et al., 2019) to establish the questionnaire framework, providing theoretical support for questionnaire design, the formulation of the intervention programme, and the selection of statistical methods.

3.2.2. Questionnaire Survey Method

The questionnaire was divided into two categories: one specifically for family caregivers and the other for kindergarten staff. It comprised three main modules: general demographic information; knowledge of HFMD; and the implementation of health behaviours related to the disease. The knowledge dimension was further subdivided into five sub-categories: basic understanding of the disease, modes of transmission, preventive measures, recognition of severe cases, and knowledge of vaccines (Gonzalez et al., 2019). Additionally, duplicate verification questions were included for subsequent data cleaning and reliability testing;Following the completion of the first draft, a small-scale sample was selected to conduct a pilot survey for optimisation. Feedback from respondents was collected and combined with expert opinions from public health lecturers to adjust the wording of questions, the formulation of response options and the layout of the questionnaire, thereby eliminating ambiguous questions and enhancing the questionnaire’s readability and scientific rigour; The formal questionnaire was distributed using an offline stratified sampling method. Paper questionnaires were distributed on-site at community markets, infant and toddler activity centres, and public and private kindergartens. Research staff provided standardised instructions on how to complete the questionnaire and collected the forms on the spot; subsequently, invalid questionnaires containing logical contradictions or extensive omissions were screened out and excluded.

3.2.3. Blended Online and Offline Intervention Approach

The online intervention tool incorporates interactive modules for severe case identification and simulated home-school communication scenarios, enabling young and middle-aged parents and kindergarten staff to engage in self-directed learning during spare moments (Wen, 2009). The offline intervention tools consist of self-developed, everyday health-themed cultural and creative products, including science-communication water bottles, stationery, classroom educational tote bags and teaching aids such as dinner plates. These products feature printed text and images relating to the prevention of HFMD, disinfection and the recognition of severe cases, designed to effectively disseminate scientific knowledge over the long term to older carers with low digital literacy and within kindergarten teaching settings; The overall intervention process involves first collecting pre-intervention baseline questionnaire data, followed by the simultaneous deployment of the app and cultural and creative products to deliver three months of continuous health education. Upon completion of the intervention period, post-intervention questionnaires are collected to analyse and compare changes in participants' awareness of HFMD and their health behaviours before and after the intervention.

3.2.4. Methods for Testing the Reliability and Validity of the Scale

(1) Reliability testing: Cronbach's α was used to assess the internal consistency of the scale; the Spearman–Brown split-half coefficient and Guttman split-half coefficient were used to test the split-half reliability of the questionnaire and determine the internal stability of the scale.

(2) Validity Testing: KMO sampling adequacy and Bartlett's sphericity tests were conducted; once the conditions were met, exploratory factor analysis was performed to assess construct validity; t-tests, analysis of variance (ANOVA) and chi-squared tests were used to conduct quantitative and qualitative hypothesis testing for the items, thereby enhancing content validity.

3.2.5. Statistical Analysis Methods

All survey data were entered into Excel for organisation, and statistical analysis was carried out using SPSS 26.0 software, with a significance level of $\alpha = 0.05$; Prior to conducting reliability and validity tests on the questionnaire, hypothesis tests on both quantitative and qualitative data for each item were first carried out to enhance the questionnaire's validity. Quantitative tests utilised t-tests and analysis of variance (ANOVA) to infer the probability of differences between variables and to determine the extent to which controllable factors influenced the research results; qualitative tests employed chi-square tests or rank-sum tests to compare the degree of deviation between actual and theoretical observations;In terms of reliability, the Spearman–Brown formula was used to calculate the reliability coefficient of the adapted scale based on the 'Chinese Residents' Health Literacy Scale for Infectious Diseases', whilst Cronbach's α was employed to assess the internal consistency of the scale. In terms of validity, factor analysis was used to evaluate the alignment between the scale items and the theoretical construct. Prior to analysis, the KMO measure of sampling adequacy and Bartlett's sphericity test to determine whether the data were suitable for factor analysis; a higher KMO value indicates better suitability. Detailed test results can be found in Table 1 at and ; statistical analysis comprised four types of methods: firstly, descriptive statistics, presenting the baseline demographic characteristics of family caregivers and

kindergarten staff in terms of frequency and proportion (%); secondly, paired t-tests to compare differences in HFMD knowledge awareness rates and health behaviour pass rates among parents and kindergarten staff before and after the intervention, thereby comprehensively assessing the overall effectiveness of the health education intervention; thirdly, Pearson's 2×2 chi-square test to conduct a univariate analysis of the association between the use of the mobile app and health-themed creative products and the population's attainment of the required level of knowledge regarding HFMD; Fourth, a binary logistic regression analysis was conducted to identify independent protective factors influencing the population's attainment of the target level of disease prevention awareness, whilst controlling for confounding variables such as age, educational attainment, caregiving status and job role, and to calculate the odds ratio (OR) and its 95% confidence interval (Jin et al., 2016).

Table 1. Summary of Reliability Statistics

Cronbach's Alpha	Part I	Value	.665
		Number of items	5a
	Part 2	Value	.654
		Number of items	4b
		Total number of items	9
Correlation between morphologies			.666
Spearman–Brown coefficient	Equal-length		.800
	Non-isometric		.801
Guttman's split-half coefficient			.800
KMO sampling adequacy measure			.806
Bartlett's sphericity test	Approximate chi-squared		642.454
	Degrees of freedom		55
	Significance		.000

3.2.6. Definition of Experimental Endpoint and Outcome Measurement Criteria

This study uniformly defines the 3-month intervention period as the sole experimental endpoint, distinguishes primary outcome indicators from secondary outcome indicators, and all statistical analyses are conducted based on this hierarchical classification standard:

(1) Primary Outcome Indicators (Core Measurement Criteria)

The qualification status of HFMD-related health knowledge is set as the primary evaluation indicator. The passing threshold is determined by the total score of the knowledge section in the questionnaire, with knowledge qualification defined as a total score of ≥60 points. The corresponding observational metrics include the HFMD knowledge awareness rate and the proportion of participants with qualified knowledge before and after the intervention. This indicator evaluates the improvement effect of two publicity carriers (virtual simulation APP and health cultural and creative products) on HFMD prevention awareness, and serves as the core dependent variable for univariate chi-square tests and binary Logistic regression analyses.

(2) Secondary Outcome Indicators (Auxiliary Measurement Criteria)

The qualified rate of HFMD-compliant health behaviors is taken as the secondary evaluation indicator. Behavioral qualification is judged according to scores from the health behavior section of the questionnaire, which supplements the evaluation of the intervention effect of integrated health education on forming routine disease prevention behaviors among family caregivers and kindergarten staff. Only paired t-tests are used to compare pre- and post-intervention differences for secondary indicators, which are not incorporated into multivariate regression models.

The timing of all questionnaire data collection is strictly standardized: baseline data before intervention are collected on-site on the day the intervention is launched, while endpoint data are uniformly recovered upon completion of the 3-month continuous integrated online-offline health education. The interval between the two rounds of questionnaires is fixed at 90 days. Confounding effects caused by inconsistent intervention duration are controlled throughout the research to ensure standardization and comparability of comparisons between primary and secondary outcome indicators.

4. Results

4.1. Descriptive Statistics of Basic Information on Families and Nurseries

4.1.1. Descriptive Statistics of Basic Family Information

The demographic characteristics of the sample of family caregivers generally reflect social reality and are well-representative; specific information can be found in Table 2: in terms of gender, prior to the intervention, 33.3 % were male and 66.7 % were female, with a male-to-female ratio of 1:2; as women bear the primary responsibility for childcare, this distribution is consistent with patterns of division of labour within the family; Age was categorised into four groups: 21–30, 31–44, 45–59, and 60 and over. The sample consisted primarily of parents of young children, with a moderate proportion of grandparents acting as carers and a relatively low proportion of older carers; this age structure reflects the current reality of childcare; Educational attainment ranges from primary school to master's degree and above, with junior secondary, senior secondary and undergraduate levels forming the majority; the undergraduate group has the highest proportion, matching the overall educational attainment level in Zhejiang Province; Caregiver roles include parents of infants and young children, grandparents and other carers such

as nannies, with a conventional structure; Occupations are categorised into nine major categories according to national standards, with stratified sampling covering all occupational categories; the demographic stratification and sample distribution for each category are both scientifically sound and reasonable.

Table 2. Distribution of Basic Household Information (n=318)

Project	Category	Number	Percentage (%)
Gender	Male	106	33.4
	Female	212	66.7
Age group	21–30	128	40.3
	31–44	130	40.9
	45–59	52	16.4
	60 and over	8	2.5
Educational attainment	Primary school	20	6.3
	Lower secondary	81	25.5
	Secondary school	56	17.6
	Higher vocational education	19	6.0
	College	40	12.6
	Bachelor’s degree	84	26.4
	Master’s degree and above	16	5.0
	Other	2	0.6
Status	Parents of infants and young children	209	65.7
	Grandparents (paternal and maternal)	25	7.9
	Other	84	26.4
Occupation	Enterprises and public institutions	42	13.2
	Professionals (teachers, doctors, lawyers, etc.)	29	9.1
	Civil servants/government	23	7.2

	employees		
	Service sector workers (catering staff, drivers, shop assistants, etc.)	58	18.2
	Farmers	38	11.9
	Workers (e.g. factory workers, construction workers, urban sanitation workers)	10	3.1
	Office workers	44	13.8
	Freelancers (e.g. writers, artists, photographers, tour guides, etc.)	6	1.9
	Other	68	21.4

4.1.2. Descriptive Statistics of Basic Information on Kindergartens

The demographic distribution of the kindergarten staff sample aligns with industry realities, and the stratification is scientifically sound. For specific details, see Table 3: prior to the intervention, the sample comprised 49 men (22.7 %) and 167 women (77.3 %), with a male-to-female ratio of 1:3.4, which is consistent with the industry's characteristic preference for meticulous female practitioners in early years education roles. Age was categorised into four groups, with young teachers aged 21–30 and middle-aged staff aged 31–44 forming the majority, whilst managers and healthcare staff aged 45–59 accounted for a certain proportion; there were very few staff aged 60 and over approaching retirement, indicating a reasonable age distribution. Educational qualifications ranged from primary school to master's degree and above, with junior secondary school and undergraduate graduates accounting for the highest proportion, which aligns with the current trends in further education and career pathways within the early years education sector. Occupations were not categorised according to the standard eight occupational classifications, but were divided into four categories—full-time teachers, childcare assistants, health and hygiene staff, and 'other'—based on the kindergarten's internal role structure.

Table 3. Distribution of Basic Information on Kindergartens (n=216)

Project	Category	Number	Percentage (%)
Gender	Male	49	22.7
	Female	167	77.3
Age group	21–30	93	43.1
	31–44	90	41.7
	45–59	28	13.0

	60 and over	5	2.3
Educational attainment	Primary school	8	3.7
	Lower secondary	70	32.4
	Upper Secondary	24	11.1
	Higher vocational education	9	4.2
	College	33	15.3
	Bachelor's degree	61	28.2
	Master's degree and above	8	3.7
	Other	3	1.4
Occupation	Nursery teacher	46	21.3
	Nursery Assistant	11	5.1
	Health and Hygiene Teacher	7	3.2
	Other	152	70.4

4.2. Difference Analysis of Primary and Secondary Outcome Indicators Before and After Intervention

This study took the awareness rate and qualification rate of hand-foot-mouth disease (HFMD) knowledge as primary outcome indicators, and the pass rate of healthy behaviors as the secondary outcome indicator. At the experimental endpoint of the 3-month intervention, changes in indicators before and after the intervention were compared between family caregivers and kindergarten staff. Paired t-tests were adopted for intra-group difference analysis with the test level α set to 0.05.

4.2.1. Primary Outcome: Differences in HFMD Knowledge Awareness Rate of Family Caregivers Before and After Intervention

The questionnaire consisted of 13 items on HFMD health knowledge. The overall HFMD knowledge awareness rate of family caregivers was 49.95% before intervention and increased to 88.85% at the intervention endpoint, with an overall growth rate of 38.90%. The awareness rate of each single knowledge item after intervention was higher than the baseline level. The paired t-test showed statistically significant differences ($P<0.05$), as detailed in Table 4.

Table 4. Summary of the number of parents aware of HFMD and their awareness rates

Title	Pre-intervention	Awareness rate (%)	After intervention	Awareness rate (%)	Difference (%)
Can you distinguish HFMD from other illnesses?	184	57.86	267	83.96	26.10
HFMD is a common infectious disease – is there no need to panic?	196	61.64	288	90.57	28.93
When do you think the peak season for HFMD is?	127	39.94	301	94.65	54.72
Is there currently a vaccine available to prevent HFMD?	138	43.40	298	93.71	50.31
Is HFMD contagious?	245	77.04	309	97.17	20.13
Do children with HFMD need to be isolated from other children after the onset of symptoms?	241	75.79	310	97.48	21.70
Do the blisters caused by HFMD leave scars or cause hyperpigmentation?	82	25.79	254	79.87	54.09
Is HFMD merely a respiratory infectious disease?	145	45.60	262	82.39	36.79
Is it possible for adults carrying the HFMD virus to pass it on to young children?	224	70.44	271	85.22	14.78
What is the first symptom to appear in a patient with HFMD?	210	66.04	283	88.99	22.96
What symptoms in a patient with HFMD indicate that the condition is severe?	66	20.75	280	88.05	67.30
By which of the following means is HFMD transmitted?	156	49.06	273	85.85	36.79
Which of the following measures can help prevent the spread of HFMD?	51	16.04	277	87.11	71.07

4.2.2. Primary Outcome: Differences in HFMD Knowledge Awareness Rate of Kindergarten Staff Before and After Intervention

The knowledge questionnaire for kindergarten teachers included 13 assessment items. The overall HFMD knowledge awareness rate of kindergarten staff was 66.74% before intervention

and rose to 93.52% at the intervention endpoint, with an overall increase of 26.78%. The awareness level of all individual knowledge points was significantly improved compared with the pre-intervention status, and the paired t-test indicated statistically significant intra-group differences ($P<0.05$), as detailed in Table 5.

Table 5. Summary of the number of kindergarten teachers with knowledge of HFMD and their knowledge rates

Topic	Before intervention	Awareness rate (%)	After intervention	Awareness rate (%)	Difference (%)
Can you distinguish HFMD from other illnesses?	168	77.78	197	91.20	13.43
HFMD is a common infectious disease – is there no need to panic?	154	71.30	210	97.22	25.93
When do you think the peak season for HFMD is?	74	34.26	191	88.43	54.17
Is HFMD merely a respiratory infectious disease?	107	49.54	209	96.76	47.22
Is it possible for adults carrying the HFMD virus to pass it on to young children?	173	80.09	211	97.69	17.59
Is there currently a vaccine available to prevent HFMD?	98	45.37	196	90.74	45.37
Do children with HFMD need to be isolated from other children after the onset of symptoms?	185	85.65	213	98.61	12.96
What is the first symptom to appear in patients with HFMD?	169	78.24	189	87.50	9.26
What symptoms in a patient with HFMD indicate that the condition is severe?	50	23.15	188	87.04	63.89
Can children develop immunity after contracting HFMD?	101	46.76	202	93.52	46.76
To prevent HFMD, ensure good personal hygiene and organise regular handwashing	198	91.67	207	95.83	4.17

sessions for children					
To prevent HFMD, ensure good indoor hygiene and ventilate the room regularly	198	91.67	203	93.98	2.31
To prevent HFMD, children's toys and tableware should be regularly and systematically disinfected	199	92.13	210	97.22	5.09

4.2.3. Secondary Outcome: Differences in Healthy Behavior Pass Rates of Family Caregivers and Kindergarten Staff Before and After Intervention

The qualification of healthy behaviors served as the secondary outcome indicator. The healthy behavior pass rate of family caregivers was 52.52% before intervention and climbed to 94.03% at the endpoint, representing an increase of 41.51%, and the paired t-test revealed statistically significant differences ($P<0.05$). In contrast, kindergarten staff already had a baseline healthy behavior pass rate of 94.44%, which only slightly rose to 94.91% at the endpoint with a growth rate of merely 0.53%, showing no statistically significant difference in behavioral indicators before and after intervention, as shown in Table 6.

Table 6. Summary of Pass Rates for Health Behaviours Related to HFMD

Study Participants	Number of respondents	Before Intervention		After Intervention		Difference in pass rate (%)
		Number of students passing	Pass rate (%)	Number of students who passed	Pass rate (%)	
Parents	318	167	52.52	299	94.03	41.51
Nursery teacher	216	204	94.44	205	94.91	0.53

4.3. Univariate Analysis of Knowledge Regarding HFMD Based on Basic Household Information

This section conducts univariate and multivariate analyses targeting the primary outcome indicator of this study (the qualification status of hand-foot-mouth disease knowledge), while the secondary outcome indicator of healthy behaviors is not incorporated into the statistical modeling in this section.

4.3.1. Analysis of the Impact of HFMD Virtual Simulation APP Usage on Knowledge Levels

This section takes the primary outcome of the study — the qualification status of hand-foot-mouth disease (HFMD) knowledge among family caregivers as the observed dependent variable, and performs univariate chi-square tests regarding the use of the APP and health cultural and creative products. Secondary outcome indicators related to healthy behaviors are excluded from this analysis.

We conducted a chi-square test to analyse whether there was a difference in knowledge of HFMD among family caregivers depending on whether or not they had used the HFMD virtual simulation app. In this context, a chi-square test (2×2) can be used for analysis, provided the following assumptions are met: Assumption 1: The observed variable is a dichotomous variable; in this study, the use of the HFMD virtual simulation app is a categorical variable with two categories: 'not used' and 'used'.Assumption 2: The observations are mutually independent; for example, in this study, the information for each participant is independent, with no interaction between them. As shown in Figure 1 .

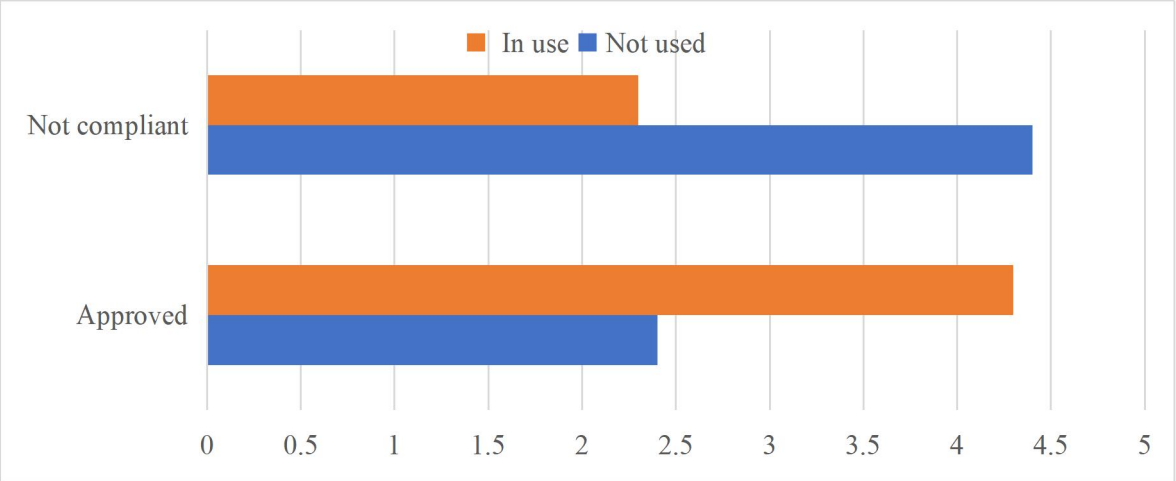

Figure 1. Distribution of knowledge levels among family caregivers before and after using the HFMD virtual simulation app

The 318 family caregivers were divided into two groups: those who did not use the app and those who did. The number of participants in each group who passed or failed the knowledge assessment was counted, and a 2×2 Pearson chi-square test was conducted. The distribution of groups is shown in Table 7.

The results of the chi-square test (2×2) showed that P = 0.037; therefore, H_0 was rejected and H_1 accepted, indicating that there is a difference in knowledge of HFMD depending on whether the app was used ($p = 0.037 < 0.05$). In other words, among family caregivers, there is a difference in their knowledge of HFMD depending on whether the app was used.

This study surveyed 318 participants, dividing them into two groups based on whether or not they used the HFMD virtual simulation app. Analysis of the pass-to-fail ratio among those who used the app compared to those who did not revealed that the pass-to-fail ratio was significantly higher in the group using the app than in the group not using it. It is likely that, after using the HFMD virtual simulation app, family caregivers engaged in systematic, interactive learning and consolidation of knowledge related to the disease. Consequently, users naturally gained a more thorough understanding of diseases to which infants and young children are susceptible, resulting in better knowledge of HFMD among app users compared to non-users.

In summary, when conducting health education on HFMD for family caregivers, the use of the HFMD virtual simulation app can be employed as an intervention to provide systematic and comprehensive teaching on childhood infectious diseases.

Table 7. Chi-square test table showing the effect of family caregivers' use of the HFMD virtual simulation app on their knowledge of the disease

Group	Failed	Pass	Total	x^2	p
Not used	45 (14.2 %)	61 (19.2 %)	106		
Use	65 (20.4 %)	147 (46.3 %)	212	4.343	.037
Total	110 (34.6 %)	208 (65.5 %)	318		

4.3.2. Analysis of the Impact of Cultural and Creative Product Usage on Awareness of HFMD

Focusing on the primary outcome indicator, namely the HFMD knowledge qualification rate of family caregivers, this section analyzes the correlation between the use of health cultural and creative products and qualified cognition. Secondary indicators such as healthy behaviors are not included in this univariate test.

We conducted a chi-square test to analyse whether there was a difference in awareness of HFMD among family caregivers depending on whether they had been exposed to cultural and creative products. In this context, a chi-square test (2×2) can be used for analysis, provided the following assumptions are met: Assumption 1: The observed variable is a binary variable; in this study, exposure to the HFMD virtual simulation app is a multi-category variable: non-use or use.Assumption 2: The observations are mutually independent; for example, in this study, the information for each participant is independent, with no mutual interference. As shown in Figure 2 .

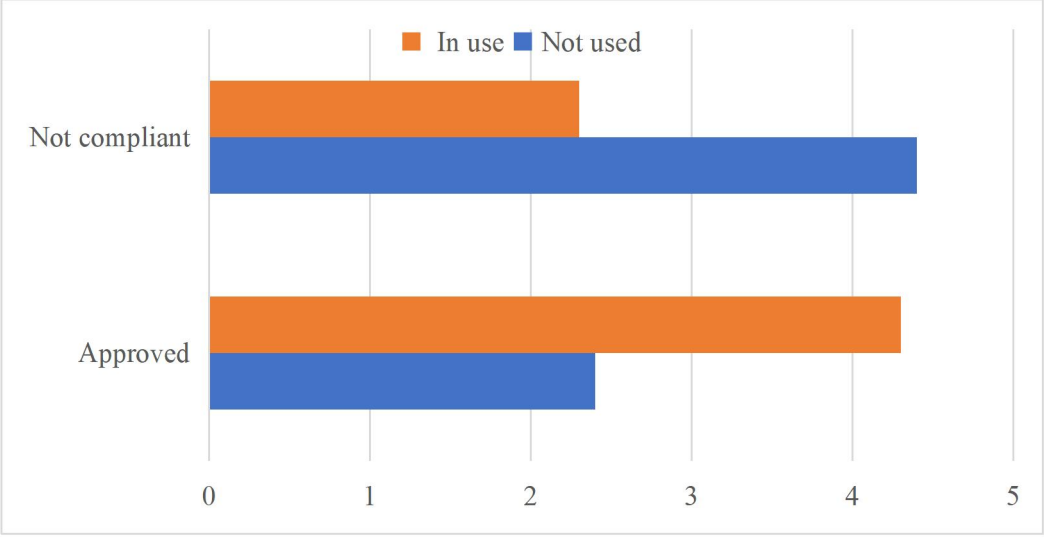

Figure 2. Distribution of knowledge levels among family caregivers before and after using cultural and creative products

Chi-square test results: $\chi^2 = 4.486$, $P = 0.034 < 0.05$; the difference is statistically significant. Exposure to health-themed cultural and creative products significantly improves the pass rate for knowledge of HFMD among family caregivers. The pass rate for those who did not use cultural and creative products was 54.6% (83/152), whilst the pass rate for those who did use them was

75.3% (125/166). The cultural and creative products feature key information on the prevention, disinfection and recognition of severe cases of HFMD printed on the surfaces of water cups, stationery and children's daily necessities. Caregivers with low digital literacy, such as grandparents, do not need to operate a mobile phone; instead, they absorb the scientific information gradually and subtly through daily use, thereby addressing the coverage gaps of purely online app-based health education and effectively enhancing disease prevention awareness among family caregivers of all age groups (Table 8).

Table 8. Chi-square test table examining the effect of whether family caregivers use cultural and creative products on their knowledge of HFMD

Grouping	Failed	Pass	Total	x^2	p
Not used	69 (21.7 %)	83 (26.1 %)	152	4.486	0.034
Used	41 (12.9 %)	125 (39.3 %)	166		
Total	110 (34.6 %)	208 (65.4 %)	318		

4.4. Univariate Analysis of the use of Educational Tools by Kindergarten Staff and Their Awareness of HFMD

This section adopts the primary outcome indicator — the HFMD knowledge qualification status of kindergarten staff as the observed variable to carry out univariate chi-square tests, with secondary outcome indicators of healthy behaviors excluded from the analysis.

The valid sample of kindergarten staff totalled 216. Using a passing mark of 60 points as the benchmark for knowledge, the impact of the use of the two types of educational tools—the app and cultural and creative materials—on the cognitive levels of kindergarten teachers and nursery assistants was analysed separately.

4.4.1. Impact of the use of the HFMD Virtual Simulation APP on the Level of Knowledge Among Kindergarten Staff

The 216 kindergarten staff members were divided into two groups: those who did not use the app and those who did. The distribution of knowledge proficiency was analysed and a chi-squared test was conducted; the results are shown in Table 9.

The sample met the requirements for a chi-square test involving independent, dichotomous variables. The test yielded $\chi^2 = 4.329$, $P = 0.038 < 0.05$; thus, the use of the app had a significant effect on the proportion of kindergarten staff achieving the required level of knowledge regarding HFMD. The pass rate for knowledge among staff who did not use the app was 66.0% (68/103), whilst the pass rate for those who did use the app was 83.2% (94/113).As kindergarten teachers and nursery assistants are responsible for the day-to-day hygiene management of all children in the nursery, the app's built-in simulations of childcare scenarios (such as the collective disinfection of toys, the management of suspected cluster cases, and guidance on home-school communication) specifically address gaps in staff knowledge regarding the identification of severe cases and the management of outbreaks. The online self-directed learning model is well-

suited to the fragmented work schedules typical of nursery settings, resulting in a marked improvement in health education outcomes.

Table 9. Chi-square test table for the relationship between kindergarten staff's use of the app and their proficiency in HFMD knowledge

Grouping	Failed	Pass	Total	x^2	p
Not used	35(16.2%)	68 (31.5 %)	103	4.329	0.038
Used	19 (8.8 %)	94 (43.5 %)	113		
Total	54 (25.0 %)	162 (75.0 %)	216		

4.4.2. The Impact of the Use of Health-Related Cultural and Creative Products on the Level of Awareness Among Kindergarten Staff

The sample of 216 staff members was categorised according to their exposure to cultural and creative products; the results of the chi-square test are available at Table 10.

The test yielded $\chi^2 = 4.375$, $P = 0.036 < 0.05$, indicating a statistically significant difference. The pass rate for knowledge among staff who did not use cultural and creative products was 66.7% (66/99), whilst the pass rate for those who did use them was 82.1% (96/117). Kindergartens have commissioned bulk orders of science-themed dinner plates, educational tote bags and class-based cultural and creative teaching aids. As a result, staff are continuously exposed to science-related text and images during their daily teaching and childcare activities. At the same time, they can utilise these cultural and creative teaching aids to conduct further science outreach to children and parents. Under the combined influence of these two factors, staff members' own understanding of disease prevention has been further enhanced.

Table 10. Chi-square Test Table for the Relationship between the Use of Cultural and Creative Products by Kindergarten Staff and Their Knowledge of HFMD

Grouping	Failed	Pass	Total	x^2	p
Not used	33 (15.3 %)	66 (30.6 %)	99	4.375	0.036
Used	21 (9.7 %)	96 (44.4 %)	117		
Total	54 (25.0 %)	162 (75.0%)	216		

4.5. Comprehensive Comparison of Univariate Results Between the Two Groups

Statistical consistency: In both the family caregivers and kindergarten staff samples, the use of virtual simulation apps and health-themed cultural and creative products was positively associated with passing the HFMD knowledge test, with P-values in both cases less than 0.05. Both online and offline educational platforms significantly improved disease prevention awareness among those involved in early childhood care and education;

Population differences: Among family caregivers, the difference in pass rates before and after using the app (21.9 %) was greater than that for cultural and creative products (20.7 %), with middle-aged and young parents showing a greater preference for online, digital, interactive learning; among kindergarten staff, the increase in pass rates achieved through cultural and creative products (15.4 %) was similar to that achieved through the app (17.2 %), indicating that both online and offline models are equally effective in enhancing knowledge among kindergarten staff.

Application Orientation: A single educational medium has limitations in reaching all target groups; digital apps are well-suited to middle-aged and young adults, whilst cultural and creative products cater to older carers with lower digital literacy. A blended model combining online apps with offline cultural and creative products can achieve equitable science communication coverage across the entire population, consistent with the overall conclusions of this study.

This study surveyed 318 + 216 participants, dividing them into two groups based on whether or not they used cultural and creative products. Analysis of the pass-to-fail ratios among those who did and did not use such products revealed that the pass-to-fail ratio for users was significantly higher than that for non-users. It is possible that school carers, whilst using cultural and creative products, tend to pay closer attention to the information regarding HFMD printed on the products. Through conscious, self-directed learning, they have gained a better grasp of key points and precautions regarding disease prevention and care; consequently, school carers who use cultural and creative products demonstrate a higher level of awareness of HFMD compared to those who do not.

In summary, when conducting health education on HFMD for school carers, cultural and creative products can be utilised as an intervention to teach the general public about childhood infectious diseases in a way that is relevant to everyday life.

4.6. Multivariate Logistic Regression Analysis

This regression model takes the study's primary outcome (whether participants achieve qualified HFMD knowledge) as the binary dependent variable and conducts multivariate analyses after adjusting for demographic confounding variables. The pass rate of healthy behaviors, a secondary outcome indicator, is not used as the dependent variable in regression analyses.

4.6.1. Binary Logistic Regression Analysis for Family Caregivers

The omnibus test of model coefficients ($P = 0.028 < 0.05$) indicates that at least one of the included independent variables has a significant effect on the 'knowledge proficiency' outcome, and the model as a whole is statistically significant. The Hosmer-Lemeshow goodness-of-fit test ($P = 0.283 > 0.05$) indicates no model fit issues, and the current combination of independent variables adequately explains the sample data. The overall predictive accuracy of the model is 65.4%, indicating that this model possesses moderate discriminatory power regarding whether family caregivers meet the knowledge criteria for HFMD.

As shown in Table 11, after controlling for confounding variables such as age, educational attainment and caregiving status, the use of a virtual simulation app and the use of health-related

cultural and creative products were both independent positive protective factors for family caregivers achieving the required level of knowledge regarding HFMD; specifically, the regression coefficient for app use was $\beta = 0.776$, $P = 0.012 < 0.05$, with an odds ratio (OR) of 2.174,with the 95% confidence interval not containing 1. All other factors being equal, family caregivers who used the virtual simulation app were 2.174 times more likely to demonstrate adequate knowledge than those who did not. The virtual simulation learning model, based on scenario-based interactive design, can systematically address gaps in the public's disease prevention knowledge and effectively increase the probability of achieving the required level of understanding;For the use of health-themed cultural and creative products, the corresponding $\beta = 0.737$, $P = 0.018 < 0.05$,OR = 2.091, 95% CI = (1.136, 3.849). The probability of knowledge compliance among carers exposed to health-themed cultural and creative products is 2.091 times that of those not exposed. Integrating disease prevention knowledge into everyday items through a lifestyle-oriented science communication approach can reach middle-aged and elderly grandparents with limited digital literacy, effectively addressing the coverage gaps of purely online health education;With regard to age, using young parents aged 21–30 as the reference group, the OR values for all age groups over 45 were less than 1 and $P > 0.05$, indicating that the overall probability of older carers achieving the required knowledge level is relatively lower; however, age was present only as a confounding variable and had no independent statistical effect;In terms of educational attainment, the P-values for the groups with college diplomas, bachelor's degrees, master's degrees and above were all less than 0.05. The higher the educational level, the higher the odds ratio for achieving the required level of knowledge. Highly educated groups demonstrate a stronger willingness to accept digital online science communication and science communication via cultural and creative media, and are able to more proactively absorb health knowledge related to HFMD.

Table 11. Three-line table of binary logistic regression analysis for HFMD knowledge proficiency among family caregivers

Independent variables	β	S.E.	Wald χ^2	P	OR	95% CI (OR)
App usage (Yes = 1, No = 0)	0.776	0.308	6.342	0.012	2.174	1.187–3.976
Whether cultural and creative products are used (Yes = 1, No = 0)	0.737	0.311	5.621	0.018	2.091	1.136–3.849
Age groups (reference group: 21–30 years)						
31–44 years	0.224	0.267	0.703	0.402	1.251	0.741–2.111
45–59 years	-0.461	0.325	2.011	0.156	0.631	0.334–1.192
60 years and over	-0.815	0.472	2.982	0.084	0.442	0.175–1.116

Independent variables	β	S.E.	Wald χ^2	P	OR	95% CI (OR)
Educational attainment (reference group: lower secondary education or below)						
Upper secondary / Vocational college	0.345	0.293	1.389	0.239	1.412	0.796–2.501
College / Undergraduate	0.683	0.281	5.910	0.015	1.980	1.142–3.433
Master's degree or higher	0.926	0.414	5.003	0.025	2.524	1.119–5.689
Status (reference group: grandparents acting as carers)						
Parental carers	0.412	0.278	2.203	0.138	1.510	0.875–2.604
Other carers	-0.187	0.304	0.379	0.538	0.829	0.457–1.503

4.6.2. Binary Logistic Regression Analysis of Kindergarten Staff

The omnibus test of model coefficients ($P = 0.016 < 0.05$) indicated that the model was valid as a whole; the Hosmer-Lemeshow goodness-of-fit test ($P = 0.140 > 0.05$) showed good fit with no significant deviation; the overall classification accuracy of the model was 68.5%, which effectively distinguished between staff members with and without adequate knowledge of HFMD.

Table 12 shows that, after adjusting for potential confounders, including age, educational attainment, and job role, the use of virtual simulation applications and health-related cultural and creative products was independently associated with a greater likelihood of achieving a passing level of knowledge about HFMD. Specifically, virtual simulation application use was a significant positive predictor ($\beta = 0.674$, OR = 1.963, $P = 0.025$), indicating that staff who used such applications had 1.963 times the odds of achieving a passing knowledge score compared with non-users. The platform's built-in simulation modules—such as those for managing cluster outbreaks in childcare settings and collective disinfection of young children—are tailored to frontline work and effectively address knowledge gaps in areas such as identifying severe cases and providing guidance to families and at home. The regression coefficient for the use of cultural and creative products was $\beta = 0.651$, $P = 0.029 < 0.05$,OR = 1.917; the probability of staff meeting cognitive standards increased by 91.7% for those exposed to cultural and creative products. The nursery's centralised procurement of science-based cultural and creative products as routine teaching aids enables staff to continuously consolidate their disease prevention knowledge through regular use, whilst also utilising these products to conduct secondary science outreach to children and parents, thereby reinforcing their own knowledge base in both directions. Results from age stratification show that, compared with young kindergarten staff aged 21–30, the OR values for middle-aged and older staff were all less than 1 and $P > 0.05$; age does not have an

independent significant effect on staff knowledge acquisition, and the kindergarten's routine hygiene management system is able to mitigate the cognitive gaps arising from differences in learning ability across age groups. With regard to educational attainment, the P-values for the junior college, undergraduate and master's degree groups were all <0.05, indicating that staff with higher educational qualifications demonstrated greater acceptance of and more efficient absorption of science communication through digital and cultural and creative formats. However, for different roles such as kindergarten staff and childcare workers, the P-values were all >0.05, suggesting that the kindergarten's standardised hygiene regulations have levelled out differences in cognitive levels across roles.

Table 12. Contingency Table for Binary Logistic Regression Analysis of HFMD Knowledge Proficiency Among Kindergarten Staff

Independent variables	β	S.E.	Wald χ^2	P	OR	95% CI (OR)
App usage (Yes = 1, No = 0)	0.674	0.301	5.012	0.025	1.963	1.088–3.541
Use of cultural and creative products (Yes = 1, No = 0)	0.651	0.297	4.817	0.029	1.917	1.073–3.425
Age groups (reference group: 21–30 years)						
31–44 years	0.195	0.282	0.477	0.490	1.215	0.699–2.109
Aged 45–59	-0.388	0.341	1.295	0.255	0.678	0.348–1.319
60 years and over	-0.742	0.495	2.248	0.134	0.476	0.180–1.259
Educational attainment (reference group: lower secondary education or below)						
Upper secondary / Vocational college	0.311	0.304	1.047	0.306	1.365	0.752–2.477
College / Undergraduate	0.642	0.290	4.904	0.027	1.900	1.076–3.353
Master's degree or higher	0.873	0.431	4.102	0.043	2.394	1.028–5.575
Post (Reference Group: Nursery/Health Teachers)						
Full-time kindergarten staff	0.356	0.289	1.515	0.218	1.428	0.811–2.513

A comparison of the two sets of logistic regression models yields two key conclusions. The first concerns a pattern of consistency:In both the family caregivers and kindergarten staff samples, the odds ratios (ORs) for the virtual simulation app and health-themed cultural and creative products were greater than 1 and $P < 0.05$. After adjusting for demographic confounding variables, both online and offline educational platforms were found to independently enhance the population's awareness of HFMD prevention and control; the blended online-offline educational model demonstrates stable and reliable intervention value. Second, the pattern of differences across populations and confounding variables: the OR values for the apps and cultural and creative products were higher among the family caregivers, indicating that these educational methods are more effective at enhancing knowledge among parents; for kindergarten staff, who have already received basic health training, the scope for further improvement through education is relatively limited;Furthermore, both sample groups demonstrated that the probability of achieving the required level of knowledge increases with higher educational attainment, whilst older adults tended to have lower levels of knowledge. Consequently, future public health outreach initiatives could adopt a stratified strategy: prioritising the distribution of offline health-themed cultural and creative products to groups with lower educational attainment and older adults, whilst prioritising the promotion of virtual simulation apps among middle-aged and young adults with higher educational attainment, thereby achieving targeted and differentiated health education.

5. Discussion

This study set the 3-month intervention as the unified experimental endpoint and hierarchically defined primary outcomes (qualified rate of HFMD prevention knowledge) and secondary outcomes (pass rate of healthy behaviors). Statistical results verified that integrated health education combining the online virtual simulation APP and offline health cultural and creative products could significantly improve the primary outcome indicators of both populations. Baseline data revealed that family caregivers had a low baseline level of primary outcomes. Although kindergarten staff possessed more basic disease prevention knowledge than caregivers, they still had cognitive gaps in core knowledge points including severe case identification and transmission routes. In terms of secondary outcomes, kindergarten staff already maintained a high standard of healthy behaviors at baseline; thus, the integrated intervention exerted no statistically significant improvement on their secondary outcomes, while family caregivers achieved a prominent increase in secondary outcome indicators.

Both univariate chi-square tests and binary Logistic regression models were constructed based on primary outcome indicators. The consistent results confirmed that both the APP and cultural and creative products served as independent positive protective factors for increasing the population's knowledge qualification rate, and the two carriers exhibited differentiated adaptability to different groups. Educational attainment was an important confounding factor affecting the level of primary outcome indicators; participants with college education or above had a significantly higher probability of reaching the standard for primary outcomes compared with those with lower educational backgrounds.

In contrast to existing foreign studies, overseas digital health education only focuses on online channels without supporting offline cultural and creative carriers to bridge the digital divide. This study innovatively adopted daily-use cultural and creative carriers to specifically elevate the primary outcome indicators of middle-aged and elderly groups, filling the gaps in existing research.The highly educated group is more willing to actively seek health information and has a higher acceptance of innovative science popularisation media (Li, 2008).

This study nevertheless has limitations:

(1) This study adopted a before-and-after self-controlled quasi-experimental design, which carries inherent methodological limitations. No parallel control groups were established in this research, including a blank control group receiving neither the online APP nor offline cultural and creative product intervention, a control group with only the online intervention, and a control group with only the offline cultural and creative product intervention. As a result, external confounding factors such as temporal effects, seasonal hand-foot-mouth disease (HFMD) science popularization campaigns, and concurrent community public health education cannot be fully ruled out as influences on outcome indicators. It is difficult to completely isolate the independent effects of the combined intervention adopted in this study and other external factors on improvements in participants' HFMD-related health knowledge and health behaviours, which limits the causal attribution of the intervention effects.

(2) Stratified sampling was conducted exclusively in Wenzhou, introducing regional selection bias. Wenzhou features region-specific characteristics in residents' health literacy, coverage of childcare institutions, family caregiving models, and penetration of digital devices. The socioeconomic, educational and caregiving composition of the sample cannot directly represent preschool caregiver populations in urban and rural areas of other provinces, central and western China, or economically underdeveloped regions, restricting the generalisability of the study's conclusions.

(3) This study only set the 3-month intervention endpoint as the sole data collection time point, with no long-term follow-up surveys conducted at 6 and 12 months after intervention completion. The long-term retention and attenuation patterns of intervention-related health knowledge and behaviours could not be observed. Short-term improvements do not confirm that the intervention delivers sustained and stable health promotion effects, leading to short-term measurement bias.

6. Conclusions

This study adopted the 3-month intervention as the standardized experimental endpoint, conducted hierarchical evaluations by distinguishing primary outcomes (qualified rate of hand-foot-mouth disease knowledge) and secondary outcomes (pass rate of healthy behaviors), and drew the following conclusions based on empirical data collected from preschool-related populations in Wenzhou:In terms of baseline characteristics of the Wenzhou samples in this study, family caregivers demonstrated an overall low baseline awareness of hand-foot-mouth disease (HFMD) knowledge; kindergarten staff possessed basic HFMD prevention knowledge but had prominent cognitive deficiencies in key contents including severe case identification and viral

transmission routes. While kindergarten staff maintained a high level of healthy behavior compliance before the intervention, the integrated online-offline intervention produced no statistically significant improvement in their healthy behaviors, whereas family caregivers saw a dramatic rise in the qualified rate of healthy behaviors after intervention. The 3-month integrated intervention combining the virtual simulation APP and health cultural and creative products significantly elevated the overall HFMD knowledge awareness rate of both family caregivers and kindergarten staff with statistically significant differences ($P < 0.05$). After adjusting for confounding variables such as age, educational attainment, and caretaking/occupational identity, the use of the virtual simulation APP and exposure to health cultural and creative products both served as independent positive protective factors for reaching the standard of HFMD knowledge among the two groups. The online virtual simulation APP better fits the learning preferences of young and middle-aged caregivers and serving kindergarten teachers, and offline health cultural and creative products can effectively reach elderly family caregivers with poor digital operation ability; the combination of the two eliminates population coverage gaps caused by a single education carrier and realizes science popularization for all target groups. The data of this study also reveal a positive correlation between educational level and the probability of reaching the HFMD knowledge standard, as participants with college education or above were more likely to achieve qualified cognition, while elderly caregivers and staff relatively mastered less disease prevention knowledge. The integrated intervention model constructed in this study, which integrates digital online interaction and offline popularization through daily cultural and creative products, adapts to two major health education scenarios including community families and kindergartens, features low implementation costs and strong hierarchical adaptability, and can be applied as a standardized intervention scheme for routine HFMD health education targeting populations related to preschool childcare.

Author Contributions:

Luyao Pan contributed to the conceptualization, methodology, and data analysis of the study. Wanting Lin provided guidance on theoretical framing and critical revisions of the manuscript. Yue Qian supervised the overall project and coordinated the research process. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement:

This study's research protocol underwent ethical review. Prior to any questionnaire distribution and intervention implementation, written informed consent was collected from all participating family primary caregivers and kindergarten staff. Every participant was fully informed of the research objectives, intervention procedures, data usage rules, and their right to voluntarily quit the study at any time without penalty.

In full compliance with the Declaration of Helsinki and international journal publishing standards for human subject research, strict data anonymization measures were enforced throughout the whole research cycle to protect participant privacy. All personally identifiable information, including names, contact details, residential addresses, affiliated kindergarten information, and children's private identity data, was permanently deleted immediately after questionnaires were recovered. Each valid sample was assigned an exclusive random digital code as the only identification marker for subsequent statistical analysis, and no individual-level raw records involving personal information entered the dataset for SPSS analysis.

For privacy protection and data security management, the original completed paper questionnaires and unprocessed electronic raw data will not be provided to any third party, including journal reviewers and readers. Only aggregated statistical indicators such as composition ratios, mean scores, chi-square and regression analysis outputs are presented in this manuscript; no complete individual original data will be disclosed in any form in published articles, supplementary materials or post-publication data sharing. All original research materials are stored in password-encrypted local storage devices accessible solely to core research team members, and all raw data archives will be securely incinerated and deleted five years after the completion of relevant follow-up studies to eliminate the risk of personal privacy leakage. No identifiable personal information appears in all tables, figures and text of the present paper.

Data Availability Statement:

Not applicable.

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Conflict of Interest:

The authors declare no conflict of interest.

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