

Article

A Multi-Modal IoT Framework for Healthy Nutritional Choices in Everyday Childhood Life

Georgios Bardis ^{1,*}, Yiannis Koumpourous ^{2,*} , Nikolaos Sideris ¹ and Christos Troussas ³ 

¹ Advanced Knowledge, Image & Information Systems Research Laboratory, Department of Informatics and Computer Engineering, University of West Attica, Egaleo Park Campus, 12243 Athens, Greece; nsideris@uniwa.gr

² Digital Innovation in Public Health Research Laboratory, Department of Public and Community Health, University of West Attica, Athens Campus, 11521 Athens, Greece

³ Educational Technology & eLearning Systems Research Laboratory, Department of Informatics and Computer Engineering, University of West Attica, Egaleo Park Campus, 12243 Athens, Greece; ctrouss@uniwa.gr

* Correspondence: gbardis@uniwa.gr (G.B.); ykoump@uniwa.gr (Y.K.)

Abstract: Policies, standards and recommendations for healthy childhood nutritional choices are well-defined and widely available, yet a significant percentage of children as well as parents and caregivers, fail to become aware and follow them despite the intense technological penetration and information abundance in everyday life. The aim of this work was to establish an IoT-integrated framework parlaying the current technological platforms' capabilities to streamline the aforementioned policies, standards, and recommendations in a transparent, highly adoptable, and attractive scheme for children while being minimally demanding for responsible adults through a set of readily available innovative services and smart devices. The rationale was to obtain information concerning nutritional choices and habits with minimum intervention through smart devices, minimizing user deviation from everyday routines in order to consolidate, visualize, and exploit this information in an engaging and motivating gaming environment, maximizing visual impact while maintaining a minimal computational footprint.

Keywords: health; obesity; IoT; multi-modal information system; QR code; smart device; WebGL



Citation: Bardis, G.; Koumpourous, Y.; Sideris, N.; Troussas, C. A Multi-Modal IoT Framework for Healthy Nutritional Choices in Everyday Childhood Life. *Electronics* **2024**, *13*, 2086. <https://doi.org/10.3390/electronics13112086>

Academic Editors: George Angelos Papadopoulos and Antoni Morell

Received: 29 March 2024

Revised: 9 May 2024

Accepted: 21 May 2024

Published: 27 May 2024



Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Childhood obesity presents a formidable global health challenge, threatening the well-being of children and their future as adults. The prevalence of childhood obesity has grown exponentially over the last few decades, leading to a genuine epidemic [1]. This issue is not confined to specific regions; it extends to Europe, the Americas, and the world at large [2].

In Europe, WHO highlighted concerning trends in childhood obesity [3]. Countries such as Greece, Italy, and Spain have witnessed alarming rates in childhood obesity recently [3]. Moreover, England reported that over a third of children aged 10 to 11 were either overweight or obese [4]. Eastern European nations have not escaped this pervasive rise [5]. The Americas are also grappling with the consequences of childhood obesity. The United States reported that nearly 19.7% of children aged 2–19 are obese [6]. In Canada, one in three children is overweight or obese. Obesity rates among children and youth in Canada have nearly tripled in the last 30 years [7]. Even Latin American countries like Brazil have experienced a doubling of childhood obesity in the last two decades [8].

Based on the most recent discoveries, it has come to light that approximately one in three children is grappling with being overweight or obese, with a notable predominance among boys [9]. Furthermore, a select group of countries, primarily those that recently had the highest rates of overweight children and children with obesity, including Greece, Italy, Portugal, and Spain, have exhibited some progress in reducing these figures. Nonetheless,

despite a 5–10 percentage point reduction, these nations continue to contend with a high prevalence of children who are overweight and obese [3].

Obesity has now reached epidemic proportions, and it is estimated that by 2030 over one billion adults globally will be obese [9]. A complex interplay of factors contributes to this epidemic. These include the increased consumption of energy-dense, nutrient-poor foods, sedentary lifestyles driven by screen time, limited physical activity opportunities, and inadequate access to nutritious food [10].

Addressing childhood obesity demands a holistic approach that engages governments, communities, schools, healthcare systems, and families. Some essential recommendations, standards, and good practices have been proposed to combat this epidemic. These encompass nutrition education in school curricula, promoting physical activity, limiting sugary beverage consumption, creating supportive environments, advocating for breastfeeding, regulating food marketing, implementing healthcare interventions, encouraging active transportation, enacting policy changes, and fostering collaboration among parents and communities [11].

Innovative technologies have also played a significant role in addressing childhood obesity. Mobile applications have emerged as potent tools for motivating and educating children about maintaining a healthy lifestyle. These apps employ gamification elements to make learning engaging and enjoyable [12]. Studies suggest that nutrition apps significantly enhance dietary behaviors and knowledge of healthy eating [13]. App-based interventions have been linked to improvements in body mass index (BMI), increased physical activity, and better adherence to dietary recommendations [13].

Furthermore, educational games focused on health and nutrition have proven to be effective in imparting essential knowledge to children in a fun and interactive manner. Games like “Fitter Critters” teach children about nutritious food choices, while “Exergaming” encourages physical activity through virtual experiences [14,15]. These games strike a balance between fun and educational content, providing feedback on performance and tracking progress to motivate children to achieve health-related goals [14,15]. Systematic literature reviews evaluating the efficiency of serious games in providing health education and behavioral changes against obesity as well as focused efforts, revealed the promising but yet-to-be-explored nature of the field’s consistent benefits [16,17].

As we confront the ongoing childhood obesity epidemic, it is crucial to adopt a multi-modal integrated framework that incorporates these diverse strategies. This paper aims to introduce and explore a comprehensive “Multi-modal IoT Framework Towards Healthy Nutritional Choices in Everyday Childhood Life”. This framework integrates nutrition education, technology-assisted interventions, smart devices, and sensors in combination with engaging educational games, aligning with established recommendations and standards to create an effective strategy for combating childhood obesity and fostering a healthier future for our children. The central concept is a video game where the nutritional habits of children in real everyday life are intuitively visualized, impacting gameplay and character development, thus encouraging and supporting healthier nutritional decisions. The connection with real-life dietary data allows for their incorporation in the game without explicit entry and mention, thus offering a less overtly didactic and thus more attractive game experience for young individuals [18]. This connection of the game world with real life is achieved through a series of smart devices [19], allowing the logging of nutritional content consumed by young individuals and subsequent computational exploitation in comparison with recommended daily allowances for each individual’s characteristics. The procedures supporting the aforementioned integration are designed to remain non-intrusive, to a feasible extent, sacrificing a certain degree of fidelity to increase their penetration and adoption in children’s and caregivers’ everyday routines. The aforementioned procedures, devices, and interconnections are presented in the following sections.

2. Aim and Goals

Childhood obesity negatively impacts the livelihood and well-being of children, also hampering their potential for healthy adult life. In an era of information abundance, strong technological presence in everyday life, and diverse nutritional options availability, it is almost ironic that children as well as parents and caregivers, are often misinformed on the issue without support from their smart devices and technological environment, allowed or led to systematically make limited and largely unhealthy choices. The policies and standards are well-defined and set, and the recommended healthy habits and alternatives are widely available and easy to discover, yet, the problem persists [20–22]. The implementation of such policies and recommendations as well as the everyday encouragement towards a healthier lifestyle, present significant difficulties when attempting them in a wide variety of social, financial, and personal circumstances arising in the lives of children and responsible caregivers [23,24].

In the current work, we present a framework that aims to assist the process of making healthier nutrition choices through the use of widely available technological platforms while maintaining a minimal deviation in the everyday life and activities of children and caregivers. The rationale is to transform the process into an involving game routine, permeating the children's day, reflecting their nutritional habits and choices into familiar gameplay elements of tasks, rewards, and features, which, in turn, are translated into game progress and affect their performance therein. In this manner, the time that would be spent for the use of a device for game playing is more likely to be invested in the framework's game environment, and the desire to excel in the latter will hopefully lead to improvements and consistent adherence to healthier habits in real life. The same environment enables the input of necessary nutritional information from a variety of sources, allowing the wide coverage of alternative choices and habits that may characterize young individuals.

In order to achieve this integration, it is required to enhance the ability to collect and process information regarding the actual nutritional choices made during the day. This could be achieved directly by the children or caregivers themselves, logging the quantities and distribution of nutrients in the meals and snacks of the day. However, it is desirable to increase the transparency and, subsequently, the efficiency and precision of this logging process. This implies the requirement for a number of modules that will be present during the steps in the process, where information regarding the nutritional content could be traced and recorded with minimal user contribution. The latter also presents the benefit of minimizing user bias or the misinterpretation of the nutritional content.

The gameplay consistently incorporates the information collected and evaluates it against recommendations and goals for a healthy nutritional lifestyle. Positive progress or divergence from goals is therefore reflected in the game character's development in a variety of forms. The most drastic effect stems from a three-dimensional depiction of a cartoon character gaining weight and presenting fatigue and incompetence during in-game tasks to reflect negative impacts or appearing fit, active, and able to advance levels to represent positive development. Alternative visualizations in the form of charts are also available for more detailed depiction and analysis of the data collected and trends implied by them.

3. Materials and Methods

3.1. Computational Component

In order to serve the aforementioned aims and goals, we had to take advantage of the currently available technologies and information, integrating them into a feasible framework. The wide penetration of smart handheld and portable devices, in the form of smartphones, tablets, and laptops, represents an established base upon which such a framework may rely for the computational component of the concept; smartphone users surpassed the mark of 4 billion in 2023 and are expected to surpass 6 billion by 2028 [25]. The computational component is responsible for the game environment to be accessed by the young individuals under adult supervision as well as for the administrative procedures

to be undertaken by the supervising adults with the possible cooperation of nutrition specialists [26].

3.2. Nutrition Fact QR-Encoding

Nutritional information is nowadays readily available in the form of largely standardized tables on most commercially available food packages [27,28]. The amount of information contained therein falls within the range of capacities of QR codes [29,30]. The standardization of the encoding of nutritional information tables as QR codes would considerably facilitate the automation of nutritional information input towards applications and frameworks, given the QR scanning capabilities of most smart platforms and penetration of QR scanning as an action familiar to a large and growing percentage of smartphone users [31].

3.3. Smart Scales and Food Packs/Backpacks

Such a minimal paradigm shift would also enable and encourage the commercial availability of smart devices equipped with QR scanners addressing nutritional concerns. In the current work, we propose smart scales with such a capability, allowing them to accurately calculate the amount of nutrients, including those connected with obesity [32] based on the weights measured and relevant QR input. Typical Bluetooth connectivity, similar to the one already available in bathroom scales, will allow the transmission of the registered nutrient information to the smart device representing the computational component of the framework. Smart food packs and backpacks are also proposed in the current work with similar communication features, i.e., QR scanning capability and Bluetooth connectivity. The former will allow on-the-spot scanning of purchased standardized foods. The latter will allow the uploading of nutritional information per compartment, corresponding to the prepared or standardized food stored therein to the smart food packs/backpacks as well as downloading from them daily usage data. The proposed compartment technology in regard to content consumption is the minimum sensing of opening/closing based on basic switch technology integrated into the zip or button securing the respective compartment. The proposed smart devices play the core role in transparent data acquisition and subsequent innovative framework capability presented below.

3.4. Dietary Information-Based Adventure Game

The availability of the aforementioned devices and configurations will allow the incorporation of dietary intake information of young individuals to the video game of the proposed framework in a transparent manner. This can eliminate the need for explicit data entry or profile creation for the young individuals, at least on their behalf, and enable the adaptation of gameplay and character attributes to the data received. Healthier dietary choices will be rewarded within the game in the form of enhanced character abilities and stamina as well as improved conformance to the gameplay challenges and/or potential to overcome final challenges. The innovative expected benefit from this is exactly the capability to create a purely entertaining, i.e., with no explicit educational content, game: reflecting actual real-world dietary information in the game's proceedings will motivate the young individuals towards healthier dietary choices and teach them the value of healthy nutrition through the benefits expected and reaped within the game tasks and adventures. The implementation of the game using pure WebGL [33] will allow the minimization of its footprint against the host device's graphics subsystem.

3.5. Framework Operational Overview

One of the prominent challenges of such an approach is the collection of data concerning the everyday nutritional choices of young individuals. These choices represent a qualitative distribution with respect to the nutritional contents of consumed foods as well as a quantitative aspect with respect to the quantities consumed throughout the day. To address this challenge, we need to introduce a collection of smart devices that are able to

record this information, imposing as minimal an intervention as possible to the nutritional daily routine. This intervention is required and cannot be avoided in order to ensure a realistic tracing of the daily meals and address the ad-hoc and not easily predictable behavior of these ages. It also has to be minimized in order to ensure the willing participation of children and maintain the feeling of a game for the overall recording process. Nevertheless, a divergence from the actual quantities and qualities is expected up to an extent, especially for those devices not designed to be always used under adult supervision. Moreover, a certain degree of feedback is required from the devices themselves in order to motivate their young users and encourage them to actuate them again whenever appropriate.

Once the information is computationally available, it will be amalgamated and presented in the gameplay to advance and differentiate the outcomes of the player's fate in the game world. Moreover, they may be reflected in the game characters' visual characteristics in a cartoonish way to stress the positive or negative aspects of the choices made. A certain degree of freedom and actual gameplay within the game world is also required to enable the adventure dimension and prevent the game from becoming overly sterile and strictly didactic. An example of such an incorporation of real-world information to the gameplay is the provision of extra abilities to the player as a reward for healthy nutritional choices during the day as well as the gradation of these abilities relative to the degree of adherence to these healthy choices, possibly exaggerating these results for emphasis, as indicatively depicted in Figure 1.



Figure 1. Indicative alternative visualizations of a game character based on nutritional choices: unhealthy choices impact “physical” character attributes, diminishing performance in gameplay [34].

The style and visual aspects of the gameplay itself may vary since the numeric and clear nature of the acquired nutritional information can be mapped in a straightforward manner to the properties of the game hero's features and abilities as well as to the challenges and tasks posed by the game environment and premise. Alternative surroundings and enactments of the same storyline are possible, ensuring prolonged interest in the overall process through re-interpretations of this mapping of real-world behavior to the virtual world's events and challenges. The game itself has to be readily available on a variety of devices with as minimal a computational footprint as possible.

The information to be acquired is aimed at recording the essential nutritional content consumed by the young individual [32] in combination with readily available information concerning everyday meals and snacks of choice [27,28,35]. The minimal set of nutritional variables to be recorded appears in Table 1. Additional variables or aspects of the parameters included therein, e.g., recommended daily intakes and specialized nutrients, may additionally be recorded upon availability in connection to specific raw materials or standardized foods.

Table 1. Nutritional elements to be recorded during framework operation.

Nutritional Parameter	Unit
Energy	kcal/100 gr
Standardized food title	-
Portion weight (standardized food)	gr
Number of portions (standardized food)	#
Custom-prepared food title	-
Raw material title (custom-prepared food)	-
Raw material weight (custom-prepared food)	gr
Portion weight (custom-prepared food)	gr
Number of portions (custom-prepared food)	#
Total fat	% weight
Saturated fat	% weight
Total carbohydrates	% weight
Sugar	% weight
Protein	% weight
Salt	% weight
Other nutrients depending on the inscription	% weight

4. Data Acquisition

In the following, we present a series of simple configurations and devices supporting the proposed framework. While not readily available, they all require a minimal paradigm shift, both by the public in the form of demand and pressure as well as by the stakeholders and industry in the form of the consensus and provision of technical and administrative solutions to become widely available and enable all the benefits from recording and evaluating information concerning nutritional choices in everyday life.

4.1. QR-Coded Nutrition Information Labels

Despite ongoing activity towards more accessible food labeling [35], current regulations for EU and USA food labels are limited to human-readable forms [27,28]. Considering the QR encoding of these labels as a viable machine-readable form, different versions of QR codes offer different capacities based on the code size and data correction level, the latter implying the data recovery percentage ability. An overview appears in Table 2.

Table 2. QR code module payload capacities per size and data redundancy [29,30].

Error Correction Level	L	M	Q	H	
Restorable Data Bytes (%)	7%	15%	25%	30%	
QR Version Side in Dots = 4 × Version + 17	Total Dots (Side²)	Payload Capacity (Bits/Module)			
1	441	152	128	104	72
5	1369	864	688	496	368
10	3249	2192	1728	1232	976
15	5929	4184	3320	2360	1784
20	9409	6888	5352	3880	3080
25	13,689	10,208	8000	5744	4304
30	18,769	13,880	10,984	7880	5960
35	24,649	18,448	14,496	10,288	7888
40	31,329	23,648	18,672	13,328	10,208

Focusing on pure binary information, the smallest version, i.e., Version 1, at the highest data correction, level H, represents the lowest data content with only 72 bits, while version 40, at the lowest data correction, level L, can carry as many as 23,648 bits. The groupings of the available bits based on a possibly restricted character set further increase the binary capacity. Alphanumeric characters, which are of interest in the current work, are paired and encoded as 11-bit units instead of the typical 16 bits required. The text content of a typical EU nutritional information table, as the one presented in Figure 2, contains 724 characters from a restricted alphanumeric alphabet. It is presented as a QR code in Figure 3: scanning the code retrieves a tab-separated version of the table text so that more sophisticated formatting of the table is possible, e.g., using XML tags. A further consensus on the standardization of the structure of the text to be encoded could offer uniformity, most importantly eliminating the need for an internet connection when scanning such a code. This formulation would allow smartphones, as well as other scanner-equipped devices, to input nutritional information and benefit from its processing and presentation locally and offline, greatly expanding the potential of relevant applications. Alternatively, for the current status quo, the adult user may enter nutritional information based on existing food labels, either manually or through scanning and OCR functionality of the proposed framework.

Nutrition Information				
	Per 100 g		Per portion of 249 g	
	%Reference Intake RI		%Reference Intake RI	
Energy	485 kJ / 117 kcal	6% RI	1 181 kJ / 284 kcal	14% RI
Fat	8 g	11% RI	19 g	27% RI
Of which Saturates	3.7 g	19% RI	9.2 g	46% RI
Carbohydrate	9 g	3% RI	23 g	9% RI
Of which Sugars	8 g	9% RI	21 g	23% RI
Protein	1.4 g	3% RI	3.4 g	7% RI
Salt	0.02 g	0% RI	0.06 g	1% RI
Vitamin C	14.81 mg	19% RI	36.91 mg	46% RI
Salt content is exclusively due to the presence of naturally occurring sodium.				
Reference intake of an average adult (8 400 kJ / 2 000 kcal)				
INGREDIENTS: Mandarin Oranges (37.9%), Light Whipping Cream (Milk), Pears (12.4%), Peaches (7.7%), Thompson Seedless Grapes (7.6%), Apple (7.5%), Banana (5.9%), English Walnuts (Tree Nuts)				

Figure 2. Typical EU nutrition information label [36].



Figure 3. Example of a QR code encoding for the nutrition information label from Figure 2 (sourced as tab-separated plain text) [37].

4.2. Smart Scale

A scale equipped with a QR code scanner will be able to identify and extract information from appropriately labeled food packaging as described in the previous section, with minimal parsing and processing of the input nutritional information. Subsequent weighing by the supervising adult or even the interested child will allow the scale to correctly assess the nutritional contribution of the specific product or raw material to the daily diet with respect to nutrient quantity and the respective coverage of daily needs. Weighing is included

in the process to eliminate the assumption of adherence to the size of the formal servings found on packages, thus increasing the fidelity of the information recorded with respect to the actual nutritional choices not only in terms of quality, as evidenced by the nutritional information label, but also in terms of quantity, as logged and connected to it through the weighing action. Moreover, the scale may be used during homemade food preparation to record quantities and characteristics of separate ingredients, thus allowing the calculation of the nutritional information for the finished meal. Registering the nutritional content of the latter at the end of such a process will allow, through the weighing of the finished product, the user to obtain a considerably close estimation of the corresponding nutrient intake. The scale is expected to locally transmit, using a Bluetooth connection, content and weight information to the user's smart device. For raw materials that may bear no nutritional information label, like fruits, meat, cheese, etc., bought in bulk at the grocery store, a functional module of the framework will contain pre-loaded information and also allow the manual input of nutritional information if preferred and the generation of the corresponding QR code on the user's device. The latter will be presented to the scale and scanned to conform with the aforementioned process. As a simpler alternative, the scale may transmit the weight devoid of nutritional information and the user may attach the latter in the relevant section of the application. The participation of the smart scale in the data exchange is visualized in Figure 4. The scale is used both during meal preparation for raw material nutritional content recording as well as for standardized food content logging.

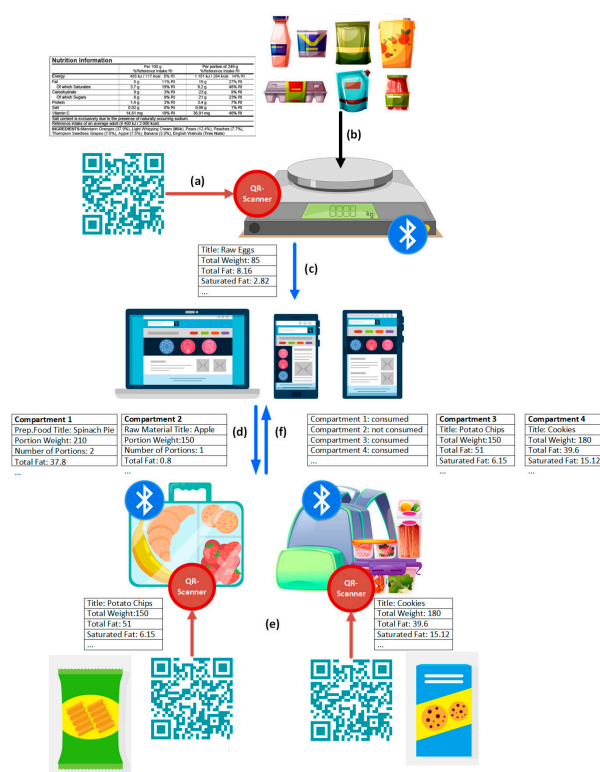


Figure 4. Data exchange among framework smart devices: (a) QR code scanning using a smart scale, (indicative QR code image used for illustrative purposes), (b) material/meal weighing using a smart scale, (c) resulting Bluetooth data transmission to a smartphone/tablet/laptop (indicative nutritional data table used for illustrative purposes), (d) portion/meal Bluetooth data transmission from a smartphone/tablet/laptop to smart food pack/backpack (indicative compartment content information table used for illustrative purposes), (e) standardized food scanning and registering away from home (indicative QR code images and nutritional data tables used for illustrative purposes), (f) end-of-day consumption data transmission with potential additional registered data from smart food pack/backpack to a smartphone/tablet/laptop (indicative compartment use data and nutritional data tables used for illustrative purposes) (icons sources [34,38]).

4.3. Smart Backpack/Food Pack

A smart backpack or food pack, equipped with several compartments, able to accept and maintain nutritional information concerning food stored in each compartment, as well as to log compartment opening and closing events, represents an elementary but prominent medium of recording nutrition-related actions. The construction of such a device can be straightforward at the hardware and computational level if we adhere to the minimum requirement of nutritional information per compartment and assume that opening implies the consumption of content by the young individual. The opening of any compartment should be accounted for only once as consumption to ensure minimum credibility; of course, even this requirement does not guarantee the actual consumption of content, but it maintains a lower degree of divergence from reality. This functionality can be supported by minimal wiring regarding the opening/closing sensing and the availability of a basic Bluetooth connection, allowing the device to receive the required nutritional information per compartment, paired with the quantity stored therein, as well as to transmit recorded usage (at the minimal level, i.e., events of opening) at the end of the day. An additional feature that would enhance the functionality of the device is a QR code scanner similar to the one suggested for the smart scale, able to scan and store nutritional information found on the wrappings of products potentially purchased by children at school or other out-of-house locations. Again, the minimal requirement assumption is that of implied consumption of the whole package whose information is scanned, whereas the compartment to be assigned should be empty and open at the time of the scanning. At the end of the day, information regarding the compartments and scanned wrappings is to be transmitted using Bluetooth to the main device to be considered in the gameplay environment. The participation of the smart food packs/backpacks in the data exchange is also visualized in Figure 4. In this case, the exchange is bidirectional: the food pack/backpack accepts nutritional information per compartment as well as additional snacks scanning during the day and, at the end of the (school) day, it provides minimal feedback on each compartment's content consumption based on the registered information and corresponding openings.

5. Functionality

The proposed framework relies on a series of simple devices and configurations to maintain data acquisition throughout the day concerning the nutritional choices and related information of young individuals. The proposed scheme suggests an educational game environment that constantly integrates elements of traditional adventure gameplay with collected information and goals and thresholds set by parents and adult supervisors, exploiting them in the form of features, rewards, and operating elements of the game environment and characters. The overview of the functionality of the framework is presented in Figure 5, while the actions involved in managing and registering nutritional information through the use of existing and proposed smart devices and configurations are detailed in Figure 6.

In reference to Figure 5, representing the top-level abstraction of the framework functionality and in compliance with the IDEF standard [39], the input arrows (left, always inward) carry incoming information either from another function (box) of the diagram or from the outer world. Data produced by any function are the result of its process, possibly applied to input data and appear on the output arrow (right, always outward). The mechanism responsible for executing each function appears at the respective mechanism arrow (bottom, always inward) and may be more than one. In the current context, the mechanisms are formally human resources, practically represented by the young individual, the responsible adult, or a nutrition specialist. Finally, the optional controls governing each function appear at the respective arrows (top, inward), in the current context practically represented by the smart devices and nutritional item packages. For example, for function A2, "Manage and Register Nutrition Information", up-to-date nutritional data and other nutritional information serve as the input; the young individual and responsible adult implement the function under the governance of smart mobile devices and specialized

outputs, appear in the diagram of Figure 6, the latter being a decomposition of function A2 of Figure 5, are strictly the mechanisms, controls, inputs, and outputs of function A2.

5.1. Impact on the Game Characters

The most obvious impact of the information acquired using the aforementioned devices and configurations is the reflection of the nutritional choices of the game character representing the young individual in an exaggerated form. The latter will allow us to maintain the humorous aspect of the game and, at the same time, to stress the impact of nutritional choices in a shorter time in order to alert the young users beforehand regarding the long-term results of their choices. Physical skills like running speed and climbing ability can be degraded due to unhealthy choices and scaled in accordance with the degree to which the nutritional goals have been met or missed. The appearance of the game avatar itself may be morphed in a manner similar to the one presented in [33], making it overweight and, thus, impeding the successful completion of certain game stages. The technical part of the game may rely exclusively on WebGL, as presented in [33], to minimize the technical footprint and maximize the portability of the game module of the proposed framework while maintaining the ability to offer attractive 3D graphics for the characters and the environment.

5.2. Impact on the Game Environment

The acquired information can also be reflected in the game environment as a series of morphological as well as functional changes representing an improvement or degradation of game conditions with respect to nutritional choices. In addition to the character's morphological alteration, the environment may reward healthy choices, e.g., by narrow openings, discouraging overweight avatars or uphill stages, and encouraging nutrition to acquire energy through healthy alternatives high in protein and low in fat.

5.3. Impact on the Other Elements of Gameplay

In addition to the physical aspects of the gameplay related to the character's appearance and abilities, nutritional choices may also be reflected in other ways within the game environment. Bonus points or special items may be awarded for reaching nutritional goals, allowing the exploration of extra stages or unlocking game characters with special features in terms of appearance or abilities. Depending on the game's premise and settings, these could also be expressed in the time dimension, e.g., making a special stage available during the weekend when adherence to a certain nutritional schedule has been achieved to a significant degree during the week.

5.4. Adult Supervisor Overview and Configuration

Critical to the success of such an environment is the active involvement of the supervising adult. Apart from the everyday actions of QR code scanning and weighing of nutritional contents, during meal preparation and smart backpack/food pack loading, the supervising adults will assume the role of the framework administrator. They will be responsible for downloading data from the smart backpacks/food packs at the end of the day and modulating their impact on the game environment. It is crucial for the success of such an IoT environment to offer the ability to finely adjust the reflection of the young individuals' nutritional choices in order to ensure that any negative impact is not extremely disappointing while any positive impact is not too easy to obtain.

Their most important task will be to establish the goals for the young individuals, in terms of nutritional content, as well as maintain and update these goals in accordance with the children's activity and physical and psychological state. The exact numbers and scheduling of these goals have to take place in cooperation with responsible specialists or, at least, in conformance with the relevant guidelines and recommendations [40].

5.5. Young Individual's Overview

Apart from the gameplay environment, which is the main focus of the young individuals' expected participation, it is foreseen to offer them access to a control panel allowing the viewing and adjustment of information connected with their everyday nutritional choices. This is desirable in order to offer an alternative aspect to the overall process and enhance the involvement and a feeling of behind-the-scenes access to the framework. One of the authors' triggering experiences for the conception and synthesis of the framework was the response of a seven-year-old nephew to the existing nutritional information labels once he was made aware of the meaning of the numbers present and their simple positive or negative interpretation of their impact on health, i.e., a lower fat percentage is better and a lower sugar content is better. In particular, it immediately became an everyday habit for him to check every nutritional information label of products either he consumed or were used in family cooking and, impressively enough, to roughly but consistently adjust quantities he consumed and even urge adults towards this direction based on fat and sugar content percentages!

6. Technical Aspects

The implementation of the proposed framework comprises a game environment, where young individuals will hopefully gain useful insight regarding their dietary choices, as well as an administration component, offering the functionality described in the previous section with respect to nutritional and consumption information management, also exploiting the proposed smart devices and configurations. For the implementation of the game environment, two main directions may be followed, represented either by the use of an existing game engine or by developing the module based on WebGL. Both choices present a number of advantages, and the choice is mostly dependent on the requirements that may be influenced by factors outside the immediate scope of the framework.

In particular, the choice of an existing game engine as the development platform will accelerate the development of a game of higher complexity in terms of appearance and gameplay, which is expected to make the game more appealing to young audiences. This is mainly due to the availability of a number of features, including a physics engine, collision detection ability, user interface handling, etc., which are inherent in a game engine's development environment [41]. Moreover, due to the popularity of the most prominent representatives of game engines, material from well-established communities, including assets and tutorials, may greatly facilitate and enhance game development in terms of appearance and gameplay. Nevertheless, this approach may restrict options for the administrative module development, which will have to be integrated into the game, as well as limit portability due to the minimum requirements posed by the game engine end result.

The alternative approach of development using WebGL and building the game environment starting from a lower coding level implies the lack of the aforementioned advantages since, while technically, the same level of complexity is achievable, it may require considerably more time and effort. However, it also offers some considerable benefits, the most obvious being the ability to maintain a minimal computational footprint for the game since the implementation using WebGL for the graphical part of the game will pose the minimum hardware requirements against any alternative for the same visual outcome. Moreover, the ubiquitous support of WebGL in modern browsers will maximize portability, whereas the integration with the administration module will be far more flexible, allowing the latter to be developed in the desired platform and achieve integration at the web level.

7. Discussion

The proposed framework unifies an array of simple smart devices, aided by minimal novel configurations in nutritional content labeling, enabling the recording and subsequent processing of the nutritional content consumed during everyday life by young individuals. The acquired data are incorporated into a video game where the characters and gameplay

attributes are affected by these dietary choices. Characters becoming more agile and responsive as a result of healthier choices, as well as gameplay favoring these attributes, allows for a game environment that is not overtly educational yet encouraging and rewarding for healthier dietary choices.

While their positive effect is yet to be systematically determined [16], educational games regarding childhood obesity have been consistently proposed addressing both aspects of dietary choices and exercise capacity. In regard to dietary choices, which is the scope of the current work, there is no similar approach incorporating real-life everyday nutrient consumption in a video game environment. In most representatives of this category of games, nutritional choices are made within the game environment and are encouraged and rewarded accordingly or, alternatively, are manually entered and subsequently evaluated. For example, “Fitter Critters” [14] approached the idea by having the player assume the nutritional responsibility of a virtual pet: nutritional choices made for the pet were reflected in indices revealing the adequacy of nutrients received, while healthier choices were encouraged in the game environment with monetary rewards and winning competitions. In “Dining Decisions” [42], the player assigns meals and snacks to three categories representing three basic levels of healthiness. A simple bilingual bingo game has been proposed to emphasize vegetable and water consumption and limit sugar intake [17] associating simple memorable rhymes with each meal and snack. Kurbo [43] attempted to engage young individuals through logging nutrient consumption and offering coaching based on manually entered data and lifestyle.

In all cases, the lack of connection with the player’s actual real-life nutritional choices allows the young individual to make healthy choices in the game environment in order to maximize game performance yet maintain potentially unhealthy dietary habits in real life. This discrepancy mainly stems from the fact that real-life dietary information is not readily available for computational processing. In contrast with exergaming, where real-life activity data may be acquired through smart device sensors in a relatively straightforward manner, dietary information, at the current status quo, requires manual data entry. The interventions we propose in the current work aim to address this burden through the QR codification of nutritional information labels and a series of simple smart devices enabling the transparent, up to an extent, logging of relevant information. This, in turn, alleviates the game environment from the need to cover and support nutrition-related content, allowing for gameplay that is less didactic and, thus, more attractive to young individuals.

8. Limitations and Future Work

The proposed framework relies on a series of smart devices and configurations to acquire dietary information with minimal intervention in the everyday routine of young individuals and provide an adventure video game rewarding healthier choices in real life with enhanced performance and improved responses to tasks and challenges in the game world. The smart devices proposed include a smart scale and food packs/backpacks with QR code scanning capabilities and Bluetooth connectivity. These devices are not readily available, thus limiting the implementation potential of the proposed framework to its full scale. An additional limitation stems from the fact that the minimal overhead for nutritional information logging relies on the availability of QR-encoded nutritional information labels on standardized foods and materials to be scanned and combined with their weight to yield analytic nutrient content. The unavailability of the smart devices may be overcome by manually logging prepared or standardized food quantities consumed as dietary choices during the day, whereas the lack of QR-encoded nutritional information labels to be combined with these quantities may be substituted using a module relying on the OCR of the currently available human-readable form of the labels. These substitutions will introduce overhead and potentially increase the probability of erroneous data due to increased human intervention, which may, in turn, discourage the systematic recording of the relevant information.

In any case, the proposed game may be implemented under the assumption of dietary information availability, either through the aforementioned alternatives or through direct data entry. Such an approach would increase the requirement for the administrative participation of the supervising adult to ensure an accurate reflection of dietary choices in the game environment. Nevertheless, it would offer a testbed for the reception and response of young individuals to the idea of a game reflecting their dietary choices in the gameplay, even if they are entered by the supervising adult or even themselves. Such a pilot game, accompanied by a survey to acquire the young individuals' feedback in regard to the full extent of the framework, could guide and further motivate the pending aspects of smart device implementation and QR-encoded nutritional information label adoption beyond the scope of research by the relevant stakeholders.

9. Conclusions

The abundance of detailed nutritional information and the wide availability of relevant healthy guidelines, as well as the increased accessibility of the general public to technological platforms, is not adequately reflected in mechanisms and tools effectively addressing childhood obesity; the latter continues to represent an epidemic that prevails and grows. In the current work, we present an IoT multi-modal framework comprising simple devices and configurations based on readily available technologies that enable the finer monitoring of nutritional choices and habits of young individuals while encouraging them towards healthier options through a game environment connected to their everyday life. Solutions proposed include machine-readable food labeling through QR codes and a series of smart devices taking advantage of them. A game environment supported by attractive 3D graphics, translating the young individuals' nutritional choices in the real world into changes in the features of characters as well as in the scenery and progress of gameplay, offers a vivid view of the effect of these choices and their positive or negative potential. The administrative module to view the information gathered and adjust goals set for the young users allows caregivers to fine-tune the game environment, conforming to the relevant guidelines in combination with daily obtained feedback and individual responses.

Author Contributions: Conceptualization, G.B.; Methodology, G.B.; Software, G.B. and N.S.; Validation, G.B.; Formal analysis, G.B.; Investigation, G.B., Y.K. and N.S.; Resources, G.B.; Data curation, G.B.; Writing—original draft, G.B. and Y.K.; Writing—review & editing, G.B.; Visualization, G.B.; Supervision, G.B.; Project administration, G.B., Y.K. and C.T.; Funding acquisition, Y.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data presented in this study are available within the article.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. UNICEF. *UNICEF Advocacy Strategy Guidance for the Prevention of Overweight and Obesity in Children and Adolescents*; UNICEF: New York, NY, USA, 2020.
2. Marta, B.; Angela, S.; Julianne, W.; Paola, N.; Ana, R.; Marta, G.S.; Else, G.; Enrique, G.-G.; Knut-Inge, K.; Gregor, S.; et al. Childhood overweight and obesity in Europe: Changes from 2007 to 2017. *Obes. Rev. Off. J. Int. Assoc. Study Obes.* **2021**, *22*, e13226. [CrossRef] [PubMed]
3. World Health Organization. Childhood Obesity: Five Facts about the WHO European Region. 2023. Available online: <https://www.who.int/europe/news/item/03-03-2023-childhood-obesity--five-facts-about-the-who-european-region> (accessed on 28 March 2024).
4. NHS Digital. Childhood Obesity in England: A Rising Concern. 2019. Available online: <https://digital.nhs.uk/data-and-information/publications/statistical/statistics-on-obesity-physical-activity-and-diet/statistics-on-obesity-physical-activity-and-diet-england-2019> (accessed on 28 March 2024).
5. Livingstone, M.B. Childhood obesity in Europe: A growing concern. *Public Health Nutr.* **2001**, *4*, 109–116. [CrossRef] [PubMed]

6. National Center for Health Statistics. Division of Health and Nutrition Examination Surveys. NHANES Interactive Data Visualizations. 2023. Designed by N. Ansai and A. Lipphardt. Prevalence of Obesity in the U.S. Population, 1999–2000 to 2017–2018. Available online: <https://www.cdc.gov/nchs/nhanes/visualization/index.htm#dashboard> (accessed on 28 March 2024).
7. Government of Canada. Childhood Obesity. 2023. Available online: <https://www.canada.ca/en/public-health/services/childhood-obesity/childhood-obesity.html> (accessed on 28 March 2024).
8. Stein, A.D. Overweight in children: A growing problem. *J. Pediatr.* **2014**, *90*, 218–220. [CrossRef] [PubMed]
9. World Obesity Federation. *World Obesity Atlas*; World Obesity Federation: London, UK, 2022; Available online: https://s3-eu-west-1.amazonaws.com/wof-files/World_Obesity_Atlas_2022.pdf (accessed on 28 March 2024).
10. Lee, A.; Cardel, M.; Donahoo, W.T. Social and Environmental Factors Influencing Obesity. [Updated 2019 Oct 12]. In *Endotext [Internet]*; MDText.com, Inc.: South Dartmouth, MA, USA, 2000. Available online: <https://www.ncbi.nlm.nih.gov/books/NBK278977/> (accessed on 28 March 2024).
11. Centers for Disease Control and Prevention. Healthcare Strategies to Prevent and Treat Childhood Obesity. 2023. Available online: <https://www.cdc.gov/obesity/strategies/healthcare/index.html> (accessed on 28 March 2024).
12. Paramastri, R.; Pratama, S.A.; Ho, D.K.N.; Purnamasari, S.D.; Mohammed, A.Z.; Galvin, C.J.; Hsu, Y.-H.E.; Tanweer, A.; Humayun, A.; Househ, M.; et al. Use of mobile applications to improve nutrition behaviour: A systematic review. *Comput. Methods Programs Biomed.* **2020**, *192*, 105459. [CrossRef] [PubMed]
13. Flores Mateo, G.; Granado-Font, E.; Ferré-Grau, C.; Montaña-Carreras, X. Mobile Phone Apps to Promote Weight Loss and Increase Physical Activity: A Systematic Review and Meta-Analysis. *J. Med. Internet Res.* **2015**, *17*, e253. [CrossRef] [PubMed]
14. Schneider, K.L.; Ferrara, J.; Lance, B.; Karetas, A.; Druker, S.; Panza, E.; Olendzki, B.; Andersen, V.; Pbert, L. Acceptability of an Online Health Videogame to Improve Diet and Physical Activity in Elementary School Students: “Fitter Critters”. *Games Health J.* **2012**, *1*, 262–268. [CrossRef] [PubMed]
15. Calcaterra, V.; Vandoni, M.; Marin, L.; Carnevale Pellino, V.; Rossi, V.; Gatti, A.; Patanè, P.; Cavallo, C.; Re, F.; Albanese, I.; et al. Exergames to Limit Weight Gain and to Fight Sedentarism in Children and Adolescents with Obesity. *Children* **2023**, *10*, 928. [CrossRef] [PubMed]
16. Dias, J.D.; Domingues, A.N.; Tibes, C.M.; Zem-Mascarenhas, S.H.; Fonseca, L.M.M. Serious games as an educational strategy to control childhood obesity: A systematic literature review. *Rev. Latino-Am. Enfermagem.* **2018**, *26*, e3036. [CrossRef] [PubMed]
17. Piziak, V. Developing Educational Games for Preschool Children to Improve Dietary Choices and Exercise Capacity. *Sustainability* **2021**, *13*, 3340. [CrossRef]
18. Galeos, C.; Karpouzis, K.; Tsatiris, G. Developing an educational programming game for children with ADHD. In Proceedings of the 2020 15th International Workshop on Semantic and Social Media Adaptation and Personalization (SMAP), Zakynthos, Greece, 29–30 October 2020; pp. 1–6. [CrossRef]
19. Fabbri, A.; Fucarino, A.; Cantoia, M.; De Giorgio, A.; Garrido, N.D.; Iuliano, E.; Reis, V.M.; Sausa, M.; Vilaça-Alves, J.; Zimatore, G.; et al. Smart Devices for Health and Wellness Applied to Tele-Exercise: An Overview of New Trends and Technologies Such as IoT and AI. *Healthcare* **2023**, *11*, 1805. [CrossRef] [PubMed]
20. Preventing Childhood Obesity: 6 Things Families Can Do. Available online: <https://www.cdc.gov/obesity/family-action/> (accessed on 27 March 2024).
21. Nutrition Standards for CACFP Meals and Snacks. Available online: <https://www.fns.usda.gov/cacfp/meals-and-snacks> (accessed on 27 March 2024).
22. Limit Screen Time. Available online: <https://www.actionforhealthykids.org/activity/limit-screen-time/> (accessed on 27 March 2024).
23. Smith, N.R.; Zivich, P.N.; Frerichs, L. Social Influences on Obesity: Current Knowledge, Emerging Methods, and Directions for Future Research and Practice. *Curr. Nutr. Rep.* **2020**, *9*, 31–41. [CrossRef] [PubMed]
24. Ayala, G.X.; Monge-Rojas, R.; King, A.C.; Hunter, R.; Berge, J.M. The social environment and childhood obesity: Implications for research and practice in the United States and countries in Latin America. *Obes. Rev.* **2021**, *22* (Suppl. S3), e13246. [CrossRef] [PubMed]
25. Number of Smartphone Users Worldwide from 2014 to 2029. Available online: <https://www.statista.com/forecasts/1143723/smartphone-users-in-the-world> (accessed on 7 May 2024).
26. Yuan, N.; Weeks, H.M.; Ball, R.; Newman, M.W.; Chang, Y.-J.; Radesky, J.S. How much do parents actually use their smartphones? Pilot study comparing self-report to passive sensing. *Pediatr. Res.* **2019**, *86*, 416–418. [CrossRef] [PubMed]
27. Nutrition Declaration. Available online: https://europa.eu/youreurope/business/product-requirements/food-labelling/nutrition-declaration/index_en.htm#shortcut-2 (accessed on 28 March 2024).
28. What’s on the Nutrition Facts Label. Available online: <https://www.fda.gov/food/nutrition-facts-label/whats-nutrition-facts-label> (accessed on 27 March 2024).
29. Lin, P.-Y.; Wu, W.-C. High payload secret hiding technology for QR codes. *EURASIP J. Image Video Process.* **2017**, *2017*, 14. [CrossRef]
30. Lin, P.-Y.; Lan, W.-S.; Chen, Y.-H.; Wu, W.-C. A Confidential QR Code Approach with Higher Information Privacy. *Entropy* **2022**, *24*, 284. [CrossRef] [PubMed]

31. Number of Smartphone Users in the United States Who Used a QR Code Scanner on Their Mobile Devices from 2020 to 2025. Available online: <https://www.statista.com/statistics/1297768/us-smartphone-users-qr-scanner/> (accessed on 7 May 2024).
32. Huang, J.-Y.; Qi, S.-J. Childhood obesity and food intake. *World J. Pediatr. WJP* **2015**, *11*, 101–107. [CrossRef] [PubMed]
33. Bardis, G.; Koumpouros, Y.; Sideris, N.; Voulodimos, A.; Doulamis, N. WebGL enabled smart avatar warping for body weight animated evolution. *Entertain. Comput.* **2019**, *32*, 100324. [CrossRef]
34. Available online: <https://www.freepik.com/> (accessed on 8 May 2024).
35. Peonides, M.; Knoll, V.; Gerstner, N.; Heiss, R.; Frischhut, M.; Gokani, N. Food labeling in the European Union: A review of existing approaches. *Int. J. Health Gov.* **2022**, *27*, 460–468. [CrossRef]
36. European Union Nutrition Facts Labels. Available online: <https://esha.com/products/genesis-rd-food-labeling-software/labels-and-labeling/european-union-nutrition-facts-label/> (accessed on 27 March 2024).
37. Available online: <https://www.the-qrcode-generator.com> (accessed on 27 March 2024).
38. Available online: <https://www.iconarchive.com/> (accessed on 7 May 2024).
39. Available online: <https://www.ideal.com/> (accessed on 7 May 2024).
40. Available online: <https://www.dietaryguidelines.gov> (accessed on 27 March 2024).
41. Salama, R.; ElSayed, M. Basic elements and characteristics of game engine. *Glob. J. Comput. Sci. Theory Res.* **2018**, *8*, 126–131. [CrossRef]
42. BAM! Dining Decisions App. Available online: <https://www.cdc.gov/healthyschools/bam/mobileapp.html> (accessed on 8 May 2024).
43. Cueto, V.; Wang, C.J.; Sanders, L.M. Impact of a Mobile App-Based Health Coaching and Behavior Change Program on Participant Engagement and Weight Status of Overweight and Obese Children: Retrospective Cohort Study. *JMIR mHealth uHealth* **2019**, *7*, e14458. [CrossRef] [PubMed]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.