Journal on Interactive Systems, 2023, 14:1, doi: 10.5753/jis.2023.3274

Development, usability, formative assessment, and story immersion of *Nutrigame*, a mHealth nutrition education app

Carina de Sousa Santos [Universidade Federal dos Vales do Jequitinhonha e Mucuri | carina.sousasantos@gmail.com]
Bruna Caroline Chaves Garcia [Universidade Federal dos Vales do Jequitinhonha e Mucuri | brunachavesgarcia@hotmail.com]
Ludiany Aparecida Moreira de Souza [Universidade Federal dos Vales do Jequitinhonha e Mucuri | ludianyap98@gmail.com]
Marliane Ferreira Gomes [Universidade Federal dos Vales do Jequitinhonha e Mucuri | fg.marliane@gmail.com]
Bianca Silva Fernandes [Universidade Federal dos Vales do Jequitinhonha e Mucuri | biancaa.fernandees_16@hotmail.com]
Elizabethe Adriana Esteves [Universidade Federal dos Vales do Jequitinhonha e Mucuri | elizabethe.esteves@gmail.com]
Etel Rocha-Vieira [Universidade Federal dos Vales do Jequitinhonha e Mucuri | etel.vieira@ufvjm.edu.br]

Abstract

The replacement of unprocessed and minimally processed foods with processed and ultra-processed ones can be a contributor to the increased prevalence of obesity amongst adults and adolescents. Mobile health (mHealth) innovations, such as mobile applications (apps), especially games, can be used to improve health behaviors and increase adolescent knowledge. The aim of this qualitative research was to describe the development, assessment, and story immersion of a mHealth nutrition education app developed to improve the food knowledge of adolescents. This study employed the stepwise approach model to the mHealth app development, according to the person-based approach and evidence-based behavior change techniques. The mHealth app was based on the concepts of the NOVA system food classification, present in the Brazilian dietary guidelines. The developed app, Nutrigame – your food guide, is a story-based serious game set in the food routine of an adolescent who needs to choose what to eat, when, where, and with whom the meals are taken. The first version of the app was tested by a group of adolescents (convenience sample, n=6, mean age: 15.8 ± 0.9 years) for 30 days. To assess usability, feasibility, engagement (user testing), and formative evaluation from the user's perspective, five individual interviews. After the last interview, the participants were required to complete a 13-item immersion scale, adapted from the narrative transportation scale to assess story immersion game. The final version of the game was adapted to meet the suggestions presented by the adolescents. All steps used for the app development are described. The gamification elements chosen led to the comprehension of the main learning contents. The mean story immersion score (30.3 ± 1.9) demonstrates the participant's involvement with the game's narrative. This study can provide useful insights to public health researchers and nutrition educators who are planning to develop a mHealth nutrition education app from a practical perspective.

Keywords: *Food knowledge, NOVA classification, Dietary Guidelines, Serious game, Game for health, Nutrition education*

1 Introduction

Overweight and obesity are major public health problems worldwide, mainly due to the prevalence increase in different age groups in recent years. From 1975 to 2016, obesity prevalence among children and adolescents (5 to 19 years old) increased more than four times (from 4% to 18%) (Abarca-Gómez *et al.* 2017). This is an alarming scenario, as adolescents with obesity are five times more likely to have obesity in adulthood (Simmonds *et al.* 2016). The replacement of unprocessed (natural) and minimally processed foods with ultra-processed ones is a major contributor to diet nutritional low quality and thus to the increased prevalence of obesity (Lane *et al.* 2021).

Unprocessed and minimally processed foods, processed culinary ingredients, processed foods, and ultra-processed foods are the four groups of the NOVA food classification system. It classifies foods according to the nature, extent, and purpose of the industrial processing they undergo. Food processing according to NOVA involves physical, biological, and chemical processes used after foods are separated from nature, and before being consumed or prepared as meals (Monteiro *et al.* 2016). The 2014 Dietary Guidelines for the Brazilian Population gained notoriety in the international media and the scientific community as its recommendations are not based on nutrient sources and food calorie content. Contrariwise, it has adopted qualitative, dietary guidelines based on the extension of food processing. The Brazilian guideline golden rule claims that natural or mini-

mally processed foods and freshly made meals must be preferred over to ultra-processed foods (Brasil 2015)[1]. However, for this rule to be complied with, knowledge and understanding of food processing, as well as the identification and recognition of NOVA food classification, are required.

Knowledge is one of the attributes of food literacy. It is a collection of interrelated knowledge, skills, and behaviors required to obtain, process, and understand basic information about food and nutrition. Additionally, it includes the competence to use the information to make appropriate decisions that lead to dietary behavior changes (Vidgen *et al.* 2014).

Adolescents' food knowledge has proven to be an important determinant of healthy food choices. Adolescents with low food knowledge showed less adherence to healthy eating habits (Tsartsali *et al.* 2009; Vaitkeviciute *et al.* 2015; Drywień *et al.* 2021). It has been shown that Brazilian adolescents had insufficient knowledge about the new dietary guidelines, especially about the NOVA classification (Chagas *et al.* 2018; Fonseca *et al.* 2019; Chagas *et al.* 2020). Therefore, the challenge of translation and teaching dietary guidelines to achieve effective changes in health behavior remains.

In this sense, mobile health (mHealth) innovations, such as the use of mobile applications (apps), represent novel opportunities to address public health challenges. According to the World Health Organization (WHO), the union of mobile technology with health and healthy eating practices can improve communication, increasing knowledge and awareness (WHO 2016; 2019). Currently, there is consistent evidence of the benefits of using mHealth apps, especially games for children and adolescents, to improve health behaviors, including initiating behaviour change, increasing motivation for small changes, and increasing knowledge (Johnson *et al.* 2016; Dias *et al.* 2018; Belghali *et al.* 2021). Therefore, games can be considered promising tools for nutritional interventions, especially among youth (Amaral *et al.* 2017).

Games designed to improve cognitive and intellectual skills are called educational games, learning games, or serious games. Serious games, when created with well-crafted stories, may facilitate nutritional education. Stories can influence cognition, affection, and, potentially, health behaviour, through immersion (Johnson *et al.* 2016; Dias *et al.* 2018; Belghali *et al.* 2021). Story immersion refers to the experience of being absorbed and engaged by it. The players may experience psychological immersion while being fully engaged in the game story, thereby paying close attention to embedded messages, and taking on a leading role in the learning process (Baranowski *et al.* 2012; Thompson *et al.* 2012; Wang *et al.* 2015; Wang *et al.* 2017). The development of mHealth interventions must be based on evidence, behavior change theories, and taxonomies. Also, the person-centred approach recommends using qualitative and iterative research to explore and test intervention with the end-user before implementation (Ferdig 2009; Czajkowski *et al.* 2015; Yardley *et al.* 2015).

Whereas adolescents generally have greater autonomy in food decisions, it is important to increase the adoption of early healthier food behaviors, so they will be more likely to be sustained into adulthood. Although serious games, when created with well-crafted stories, may facilitate nutritional education, in Brazil, it is still an unexplored area. Few mHealth apps were found whose aim is to increase adolescents' food knowledge (Chagas *et al.* 2018; Ribeiro *et al.* 2019; Brito *et al.* 2020; Fossari *et al.* 2023). Therefore, this study describes the development, usability, formative assessment and story immersion of a mHealth nutrition education app to improve the food knowledge of adolescents. The mHealth app is based on the concepts of the NOVA classification, the foundation of the 2014 Dietary Guidelines for the Brazilian Population. In this sense, the authors should better present the article's objectives, methodology, main results, and contributions to the scientific community in this section.

2 Method

2.1 Study Design

The game was idealized by researchers in the field of nutrition and human health (researchers: CSC, BCCG, EAE and ER-V). Game development and design were conducted by a game company (Glitch Factory), under the supervision of the researchers. For the development of the app we used a stepwise, person-based approach, guided by the Obesity-Related Behavioral Intervention Trials (ORBIT) (Ferdig 2009; Czajkowski *et al.* 2015; Yardley *et al.* 2015) (**Table 1**). The study was approved by the Research Ethics Committee of the Universidade Federal dos Vales do Jequitinhonha e Mucuri and all the participants provided written informed consent (# 12218819.0.0000.5108).

2.1.1 Step 1 - Theoretical underpinning and conceptualization

Based on literature and taxonomy; based that the knowledge is an attribute of food literacy that has been identified as a gap in the ability of youth to make healthy eating choices: the learning goal, the learning approach, the learning content, the behaviour change techniques, and the communication's way were determined (Michie *et al.* 2009; Michie *et al.* 2013; Brasil 2015; Ivens *et al.* 2016; Johnson *et al.* 2016; Amaral *et al.* 2017; Chagas *et al.* 2018; Dias *et al.* 2018; Simons *et al.* 2018; Fonseca *et al.* 2019; Brown *et al.* 2020; Chagas *et al.* 2020; Belghali *et al.* 2021).

2.1.2 Step 2 - Developing the mHealth nutrition education app

Naming process. The mHealth app name creation process involved 8 steps, according to Wheeler (2013).

Dimensions and gamification elements. An analysis was carried out in the Google Play and Apple Store to identify the

[1] https://www.gov.br/saude/pt-br/assuntos/saude-brasil/publicacoes-para-promocao-a-saude/guia_alimentar_populacao_brasileira_2ed.pdf/view

most popular caring games, which were used as a reference to explore the gamification dimensions and the more attractive and currently acceptable elements of user's interest. The games chosen as references were: Bubbu My Virtual Pet® (Pilcom), Plant Nanny® (Fourdesire), and Pou® (Paul Salameh). These 3 games exceed 10 million downloads. Based on these games and the Taxonomy of Gamification Concepts for Health Apps (Schmidt-Kraepelin *et al.* 2018), the team defined the dimensions and gamification elements of the concepts of art and design that would best deliver the content to be taught to adolescents: narrative, plot, and user identity; gameplay; player advancement; and reinforcement.

Table 1. The stepwise approach and determinant phases based on the developmental steps for mHealth interventions.

Step 1: Theoretical underpinning and conceptualization	Learning goal Learning approach Learning content Communication Behaviour Change Techniques
Step 2: Developing the mHealth nutrition education app	Naming process Gamification elements and dimensions: ▪ Narrative, plot and user identity ▪ Gameplay ▪ Reinforcement ▪ Player advancement
Step 3: User testing, formative evaluation and story immersion	**Usability:** refers to the technical aspects of the app and the interface with the game. **Feasibility:** refers to how the strategy is realistic **Engagement:** refers to how the target audience interacted with the app **Formative assessment:** refers to the interaction between gameplay, narrative and content. It allows a preliminary evaluation of the game learning objective achievements **Story immersion:** refers to the experience of being absorbed and engaged by narrative

2.1.3 Step 3 - User testing, formative evaluation, and story immersion

The first version of the mHealth app was evaluated by the team and approved for step 3. In this step, a convenience sample of adolescents (n=6), consistent with the game's target audience, was selected to test the mHealth app for 30 days. The aim of this step was to assess usability (download and install; correction and understanding; visibility and structure; avatar; gameplay; overall impression), feasibility (completeness; relevance), engagement (user testing), and formative evaluation (about gamification elements and dimensions used) rom the user's perspective. So, five individual interviews with each adolescent were conducted (Maramba *et al.* 2019). To stimulate the participants' communication (Charters 2003), an interview protocol, based on the Iterative Convergent Design for Mobile Health Usability Testing approach was developed (Alwashmi *et al.* 2019). The interview was composed by questions adapted from questionnaires used in similar studies **(supplementary appendix 1)** (Wang *et al.* 2015; Simons *et al.* 2018). After the last interview, the participants were required to complete a 13-item immersion scale, adapted from the narrative transportation scale to assess story immersion game **(supplementary appendix 2)** (Green *et al.* 2000). The adolescents rated their levels of agreement with statements on a 3-point Likert scale (1 = do not agree; 2 = somewhat agree; 3 = agree a lot). The score was summed, and the possible scores ranged from 13 to 59.

2.2 Data Analysis

Continuous data were presented as mean and standard deviation or median, minimum, and maximum range. All interviews were recorded in audio and video and transcribed verbatim.

Qualitative content analysis was carried out by means of a systematic floating, reading of all the transcribed material, and the answers were then grouped according to each question of the interview protocol. This methodological approach was based on the content analysis technique (Bardin 2010). The main answers were compiled, then aligned by question and presented in a tabular form. To preserve the anonymity of the participants, each adolescent was assigned a code (A1 through A6) for the description of the results.

3 Results

3.1 Step 1

The learning goal. The goal was to improve the adolescents' food knowledge about the 2014 Dietary Guidelines for the Brazilian Population. Knowledge is an attribute of food literacy that has been identified as a gap in the ability of youth to make healthy eating choices (Chagas *et al.* 2018; Fonseca *et al.* 2019; Chagas *et al.* 2020).

The learning approach. Gamified mHealth apps are a promising way to pursue food literacy (Johnson *et al.* 2016; Amaral *et al.* 2017; Dias *et al.* 2018; Belghali *et al.* 2021). However, game immersion has received scant empirical investigation in mHealth intervention research. Thereby, a game with an immersive story and characters similar to the adolescent was chosen as the learning approach to the mHealth app to improve food knowledge.

Table 2. The mHealth app learning content.

The 2014 Dietary Guidelines for the Brazilian Population	***The golden rule:*** Always prefer natural or minimally processed foods and freshly made dishes and meals to ultra-processed foods. 1. Turn unprocessed (natural) or minimally processed foods, in great variety, mainly of plant origin, the **basis of your diet.** 2. Use oils, fats, salt, and sugar **in small amounts** when seasoning and cooking unprocessed (natural) or minimally processed foods, and to create culinary preparations based on unprocessed or minimally processed foods. 3. **Limit the consumption** of processed foods, consuming them in small amounts as ingredients in culinary preparations or as part of meals based on natural or minimally processed foods. 4. **Avoid consumption** of ultra-processed foods. 5. Eat regularly and carefully in appropriate locations and, whenever possible, in company.
The learning content	● To teach how to choose food according to its processing level, following the NOVA food classification system (qualitative choice) rather than food calories and nutrients (quantitative choice): **Group 1 - the basis of diet:** Unprocessed and minimally processed foods **Group 2 - use in small amounts:** Processed culinary ingredients **Group 3 - limit consumption:** Processed foods **Group 4 – avoid consumption:** Ultra-processed foods ● To teach the short and long-time impact of each food choice. ● To teach the concepts of commensality and the act of eating, emphasising the circumstances – time and focus, location and company – that influence the food choices and the pleasure caused by meals. ● To teach the short and long-term impact of each act of eating.

The learning content. The content was defined based on five from the ten recommendations of the 2014 Dietary Guidelines for the Brazilian Population (Brasil 2015) (**Table 2**).

Communication. The app uses pieces of information, instructions, and prompts/cues, in text form, to increase knowledge and to encourage the next proper choice during the game. The text development was guided by the best practices for translating scientific knowledge for dietary guidelines. The text was short (≤ 3 sentences long), concise, direct, and employed simple language. It conveyed the most important information at the beginning (anticlimactic) and was explicit in the information released (Ivens et al. 2016). A communication specialist reviewed the text and integrated colloquial terminology without compromising the precision of the communicated information. In addition, when necessary, message length was condensed or divided into two or more sentences to turn it simpler for reading. A communication specialist reviewed the text and integrated colloquial terminology without compromising the precision of the communicated information. In addition, when necessary, the message length was condensed or divided into two or more sentences to make it simpler to read.

Selecting behaviour change techniques. The evidence-based behaviour change techniques were incorporated into the mHealth app to illustrate how the knowledge acquired could be applied to real-life dietary decisions and increase the attitude related to these decisions. These techniques were identified as a replicable and potentially effective approach to include in mHealth apps (Michie et al. 2009). Therefore, based on literature and taxonomy, five behaviour change techniques were chosen: feedback on behaviour; feedback on the outcome of behaviour; instruction on how to perform the behaviour; prompts/cues and associative learning (Michie et al. 2013; Simons et al. 2018; Brown et al. 2020) **(Table 3)**.

3.2 Step 2

3.2.1 The naming process

Nutrigame – your food guide (from Portuguese, Nutrigame – seu guia alimentar) was the chosen name. The word "nutri" comes from nutrition, which is more popular and used in colloquial language as a synonym for food. The word "*game*" was chosen to literally represent the mHealth app type. It was adopted in English because it is a word incorporated into the colloquial Brazilian vocabulary. The use of the grammatical apposition "– *your food guide*" was chosen to summarize the content of the game while emphasizing the 2014 Dietary Guidelines for the Brazilian Population (Brasil 2015).

3.2.2 The narrative, plot, and user identity

Nutrigame – Your food guide is a story-based game set in the food routine of an adolescent who needs to choose what to eat, when, where, and with whom the meals will be taken. The plot is driven when the adolescent consults with a dietitian who provides guidance on how to choose healthy foods and have healthy eating attitudes. After an interval of 6 days, the adolescent returns to the dietitian to get feedback on food choices and how they have affected health. To initiate the game, the player needs to choose a female or male avatar and name it. The avatar is an adolescent character created to have diverse appearances with different racial backgrounds and facial features (**Figure 1**). Population (Brasil 2015).

3.2.3 Gameplay - feeding the avatar

To feed the avatar, the player assembles a meal from a menu with 40 food options. The foods and homemade culinary preparations presented on the list were strategically chosen to teach about how foods are classified according to the extent of processing, based on the concepts of the NOVA food classification system (Monteiro *et al.* 2016).

Table 3. Relationship among learning content, gamification elements and dimensions used, and the behavior change techniques implemented in the Nutrigame.

Learning content	Gamification elements and dimensions	Behavior changes techniques
NOVA classification Act of eating and commensality	Tutorial with the dietitian	4.1. Instruction on how to perform the behavior 7.1. Prompts/cues
NOVA classification	Food menu with descriptions, positive and negative reinforcement, instructions	2.2. Feedback on behavior 4.1. Instruction on how to perform the behavior 7.1. Prompts/cues
Act of eating and commensality	Location, company, and time	4.1. Instruction on how to perform the behavior 7.1. Prompts/cues
NOVA food classification system Short-term impact of food choices	Short-term indicator	2.2. Feedback on behavior 7.8. Associative learning
NOVA food classification system Long-term impact of food choices	Long-term indicator	2.2. Feedback on behavior 7.8. Associative learning
Long-term impact of choices	Avatar's physical form and mood	7.8. Associative learning
Act of eating and commensality	The avatar's faint	7.8. Associative learning
NOVA food classification system	Food log	2.7. Feedback on behavior outcome(s)

3.2.4 Gameplay – location, company, and mealtime

Every time the player feeds the avatar, he can choose between three locations: the kitchen, the living room with the TV on, and the cafeteria. The player can also choose whether or not the meal will be enjoyed in a company. The passage of time also counts. The clock marks the avatar's fasting time.

3.2.5 Reinforcement

At each gameplay, through direct dialogue, the players are repeatedly exposed to information, instructions, and prompts/cues via text. The dialogues communicate, teach and allow avatar development as it is possible for the player to improve future choices along with the narrative. At the beginning of the game, a dietitian explains how to play and gives all instructions and recommendations. At the end of the game, the avatar is referred to the dietitian again who gives feedback on food decisions based on the food log. The food log provides health long-term indicators and a food choice analysis according to NOVA classification.

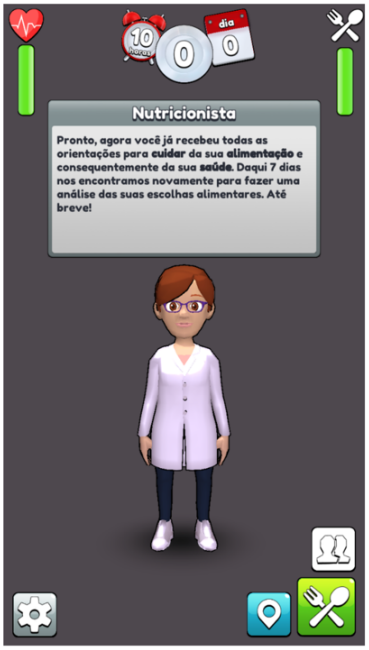
For each food chosen to compose the meal, a text box with 4 pieces of information appears. (a) The food classification, according to NOVA. (b) A reinforcement or an instruction: a positive reinforcement for choosing unprocessed foods, minimally processed foods, and homemade culinary preparations (you made an excellent choice); a recommendation for choosing processed food (should be consumed in moderation) and for ultra-processed food (should be avoided); (c) a brief explanation of the processing extent of the chosen food, to teach the player NOVA classification. When the player chooses a culinary preparation, an explanation highlights the importance of homemade food and its balanced combination with culinary ingredients; (d) A tip on how to combine the chosen food with others, or when it is an ultra-processed food, instructions on how to make healthy changes. Then the player is free to continue with the choice or to change it. If the location choice was not appropriate (i.e.: the TV room), and if the avatar ate alone, a tip/instruction pops up after the meal, to show the player the best choices for the next meal.

The instruction is always to eat in clean, comfortable, and quiet locations, without stimuli and unlimited food amount consumption. And, whenever possible, to take the meal in the companion of others, reinforcing the concept that a healthy diet is not associated only with the act of food intake (Brasil 2015).

3.2.6 Player advancement

The players' advancement and performance are presented via the qualitative progress indicators. The short-term indicator (feed indicator) reflects the impact of feeding choices during a single day. When the player chooses meals containing unprocessed foods, minimally processed foods and homemade culinary preparations it goes up. Otherwise, the indicator goes down when processed and ultra-processed foods are chosen. When the avatar spends a long time without being fed, this indicator also goes down. It is reset every morning, allowing the player to change food choices. There is no connection between food calorie content and the indicator modification. Food quality, according to the processing extension, is what matters (Monteiro *et al.* 2016).

The long-term indicator is the overall health indicator. It changes gradually over the days according to gameplay, and in the end, it reflects the sum of choices the player has made throughout the game. Alterations in this indicator are accompanied by a change in the avatar's physical form and mood. As health improves, the indicator goes up and the avatar loses weight and improves mood. As health worsens, the indicator goes down and the avatar gains weight and worsens mood. According to the 2014 Dietary Guidelines for the Brazilian Population, controlling body weight instead of counting calories is a simple and efficient way to know if the amount of food consumed is adequate or not (Brasil 2015). The two possible game outcomes depend on the progress of this indicator: when not reset, at the end of the 6 days the avatar will be evaluated by the dietitian. When reset, the avatar passes out and goes to the hospital, ending the game. Hence, the goals are to allow the player to understand how food choices impact the avatar's health, that food impact on health is gradual, and to teach the player how to make better food choices.



Translation

Okay, now you have received all the guidelines to take care of your diet and your health. In 7 days, we will meet again to analyze your food choices. See you soon!

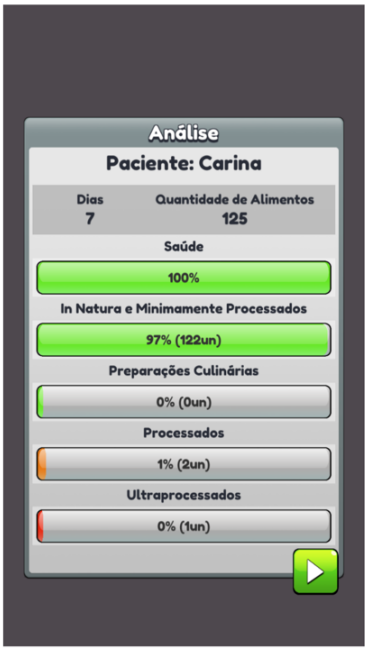
Game day 1

Game day 6

Menu with 40 food options and homemade culinary preparations.

Translation

Banana. Unprocessed food.
You made an excellent choice! Fruits come directly from nature, ready to be consumed. Fruits such as bananas, apples, oranges, pears, persimmons and guava are excellent snack options during meal intervals and you can take them with you anywhere. Make natural foods the basis of your diet.



Translation

Food log analysis
Character name's
Days - Food amount
Health (long-term indicator's results)
Unprocessed and minimally processed foods
Homemade culinary preparations
Processed foods
Ultra-processed foods

Figure 1. Screenshots of the mHealth app: *Nutrigame - your food guide*

3.3 Step 3

The first version of the app was tested by a small group of adolescents (convenience sample, n=6, mean age: 15.8 ± 0.9 years) for 30 days. The participants owned different brands of Android and IOS smartphones.

No problems due to technical aspects of the app and the game interface were reported. Overall, the adolescents were positive about the game and the avatar design **(Table 4A)**.

Participants gave two recommendations. About the food menu, the participants suggested increasing the options because they would like to feed the avatar with the same foods

Table 4. Example user's perspective quotes derived from the qualitative analysis of 'participants' interviews.

Dimensions evaluated	Example user's perspective quote
A. User testing: usability Download and Install Correction and understanding Visibility and structure Avatar Gameplay Overall impression	***(A1)*** *[...] the interface is very intuitive. I think everything is well planned, I understood a lot. I thought it is very simple to understand. I thought it was cute* [about the avatar]. ***(A5)*** *I thought it is super interactive, it explains everything, (...) it was super cool, I liked it. I think it's very easy to understand. When you go to feed the avatar, you click on the food and the information appears. I thought it was normal* [about avatar].
B. User testing: feasibility Completeness	***(A3)*** *I would put more food options in the game. [...] I had doubts about classifying the food, for example, sometimes it wasn't there, then I had to take a look, to compare what came closer, you know? Sometimes I drink coffee too, but then I put it as juice. Apart from that, I thought it is very good, and very intuitive to use.* ***(A5)*** *I think it could have a message, such as "your avatar is going to pass out".*
B. User testing: feasibility Relevance	***(A1)*** *Yes. [...] Home-made popcorn, for example, I thought it was super fatty food, you know? But, if prepared with a little oil and a little salt, it is healthy. Some foods I had no such idea.* ***(A5)*** *Yes, because it makes you understand more, for example, if you choose an ultra-processed or a natural juice, you can see the difference.* ***(A6)*** *Yes. I thought it was cool, innovative, you know, because we don't see apps such as this one, that have both a game and [health] information [...], that tell us that is better for us to eat well [...] that we can live better and learn with the game and take it to the real life.*
C. Engagement (User testing)	***(A1)*** *I would give it a 9* [how much did like] [because] *if it had more food options and we could make associations with the food we eat,* [It would be important] *even to have more motivation to play.* ***(A2)*** *I would give 3* [how did difficult] *because in the first days, it's hard to remember to feed the avatar, but after a while, you learn what you can give her* [avatar], *so she'll be fine.*
D. Formative evaluation About food choice impact on the food indicator	***(A1)*** *The more you add ultra-processed [...] the more they* [indicators] *decrease, and as for vegetables, fruits, things that are made at home, [...] they increase. [...]* ***(A4)*** *The processed food lowered it a little and the ultra-processed lowered it more. When I chose the soda, it went down a lot because ultra-processed* [food] *is more harmful to health.*
D. Formative evaluation About the difference between the food and health indicators	***(A1)*** *[...] because in the beginning, health did not come out of the red. With the first day it would not change that much, right? But then, over the days, I kept choosing healthier foods, her* [avatar] *health was increasing, then it would turn green, it was like the food indicator, you know? I think it is over time that it gets better if she is consuming healthier things. Because in association with our normal life, if you have high cholesterol, and if you eat healthy for a day, it will not improve overnight.* ***(A4)*** *The health* [indicator] *took longer to rise than the other. I think it's not only one food that will affect health. It is a set of several ones. It increased little by little.*
D. Formative evaluation About the choice of the meal location, and the decision whether or not it would be held in company	***(A2)*** *Yes. It makes you appreciate the food more, also because it is a time for socializing, [...], as it said* [the game] *it would be good if you didn't have a cell phone or television around, so* [you're] *not distracted and eat so quickly.* ***(A6)*** *I think this makes a lot of difference in the meal, for example, when you go to eat alone, you eat faster. When you're with someone you eat less, and talk more, then it's different. [...] when the television is on, it may be that he eats and looks at the television and ends up eating more than he should, or he doesn't pay attention to what he's eating.*
D. Formative evaluation About the avatar outcomes	***(A1, A4)*** *He fainted. I think it was because he didn't eat for a long time.* ***(A1)*** *At the end of the week, I noticed that she changed, right? I think she got a little thinner. Because health increased as I gave her more natural foods and culinary preparations.* ***(A3)*** *I've noticed it around the last few days. I remember that at the beginning, she was quite chubby, and at the end when the health bar was higher, she was thinner, I had this impression.*
E. Story immersion	***(A1)*** *[...] because sometimes I wanted to do it according to what I ate that day, you know? I wanted to give the avatar the same thing I ate.* ***(A3)*** *I eat a lot of bread, so I gave it* [at the avatar]. *But I think I had a good diet.* ***(A5)*** *[..] I ate 0% of ultra-processed. That's good, I think. Processed 10%, culinary preparations, which I'm very used to, was 35%, and in natura and minimally processed 55%.* ***(A6)*** *[...] most of the time I ate in the kitchen because it's not very good to eat with the television on, but probably one day or two I must have eaten in the living room.*

they ate in their routine during the test period. About the notifications, they suggested the inclusion of a smartphone notification to remind them to take care of the avatar. Despite the suggestions, all adolescents would recommend the app to others **(Table 4B)**.

The adolescents liked the game a lot (median of 8.75, range, 8 - 10) and considered it with a low level of difficulty (median of 2.5, range, 1 – 4). According to the comments, the scores the adolescents attributed to the game were due to its missing aspects **(Table 4C)**.

In the formative evaluation, the adolescents showed the expected associations between food processing and its respective impact on the short-term indicator. They were able to perceive the difference between the feed and health indicators as short and long-term indicators. The answers about the circumstances - time and focus, location, and company, showed that adolescents thoughted about the behaviours that influence eating. Thus, the adolescents showed associative learning between eating with someone and in the appropriate location with a protective, health practice. They also made the expected associations between regularity of meals, type of food, change in physical shape, and health **(Table 4D)**.

The mean story immersion score was 30.3 ± 1.9, a value superior to the median (26, range, 13 – 39), therefore, demonstrating the participant's involvement with the game's narrative. The story immersion was also seen in the player mirroring the avatar. During the interviews, some answers showed that the players were referring to the avatar in the first person and they would like to feed the avatar the same foods they were eating at that time **(Table 4E)**.

3.4 Final version of mHealth nutrition education app

The final version of the game was adapted to meet one of the two suggestions presented by the adolescents. As part of the reinforcement dimension, a push notification was included in the game to remind the adolescents to take care of the avatar. The inclusion of more food options in the menu was not carried out because, initially, the goal was to teach about the classification of foods according to the NOVA classification, based on a list of the most common foods in the Brazilian diet. The mHealth app is free and compatible with Android and iOS devices, and it is copyrighted by the Brazilian National Institute of Industrial Property (#BR512020000765-1).

4 Discussion

This study described the development steps and the assessment of a new mHealth nutrition education app for adolescents: the *Nutrigame - your food guide*. To our knowledge, this is the first study documenting the development of a new mHealth app focused on improving adolescents' knowledge of the NOVA food classification system.

The app was tested by a small group of adolescents, for 30 days. Nielsen *et al.* (1993) showed that usability testing with only 5 participants will reveal 85% of usability problems. In our study, the user test demonstrated that the chosen dimensions and gamification elements lead to the comprehension of the main concepts about the extension of food processing and healthy commensality attitudes. In the story immersion, the adolescents mirrored the avatar, demonstrating the involvement with the game's narrative - a critical determinant of its immersive quality that is essential to the learning goal (Green *et al.* 2000).

The game uses several dimensions and gamification elements (Schmidt-Kraepelin *et al.* 2018). The menu was designed to simulate real-world dietary choices, which may increase confidence in making real-life healthy eating decisions (IBGE 2010; Vidgen *et al.* 2014). For example: as the gamer plays, it is possible to make choices that lead to different endings; the performance is evaluated by several indicators; the player is repeatedly exposed to information and instructions via text.

Players' recommendations about the game – to increase the menu options, were not followed. The game's persuasive intention is to teach food classification basic concepts and the circumstances (time and focus, space and companion) that affect eating. After learning the concepts, the player should be able to classify and choose food in daily life, independent of its presence on the game list. Moreover, with this knowledge, adolescents can increase their autonomy in future food choices and can positively change attitudes regarding choosing healthy foods. Our initial data indicates that this goal can be achieved with the game, in accordance with studies that demonstrated results this nature using serious games and food knowledge (Wang *et al.* 2015; Wang *et al.* 2017; Brown *et al.* 2020; Chagas *et al.* 2020). Thus, the Nutrigame – your food guide, an mHealth nutrition education app, is a nutritional education tool, attractive to its audience, accessible and easy to use. It has the potential to improve knowledge and encourage autonomy and the intrinsic motivation to make healthy choices in real life as much as possible. These are currently been investigated in a clinical trial. According to the ORBIT model, phase 1 is shown in this paper (Czajkowski *et al.* 2015). Currently, as a part of phase 2 (preliminary evaluation), the effectiveness of the game as a public nutrition education tool is being evaluated in a randomized clinical trial study with a control group. The clinical trial is registered in The Brazilian Registry of Clinical Trials (ReBEC) (#RBR-2h29zc).

This study includes some crucial strengths. An interdisciplinar team of experts was engaged in the app development process, which is a feature of high-quality digital interventions, as it ensures that all the dimensions are represented (Whittaker *et al.* 2012; Michie *et al.* 2017). The game was developed based on theory and evidence, which is a determinant of effectiveness (Czajkowski *et al.* 2015; Yardley *et al.* 2015). During user testing, several interviews were employed, associated with the use of mixed qualitative and quantitative research methods (think-aloud interviews, semi-structured interviews, and questionnaires), as recommended (Alwashmi *et al.* 2019). The use of multiple methods in this study provided a set of data about the user experience, and, consequently, it ensured that the game met the needs of the

target audience. Thus, this research supports the recommendations from research and OMS which strongly emphasise the importance of a gradual and iterative approach before conducting a randomized clinical trial, as they ensure the best chance of developing new and effective tools to improve health (WHO 2016; 2019).

This work and app have implications for public health. This work provides useful insights to public health researchers and nutrition educators planning to develop a mHealth nutrition education app from a practical perspective. Another one is the development of a new tool that can support educators in public health interventions, especially those related to adolescents' food literacy. Nutrigame - Your Food Guide is attractive to its audience, accessible, and easy to use. This app can also be used in research that aims to investigate alternative strategies for health education. The Nutrigame - Your Food Guide was awarded the Best Game for popular vote in the SBGames 2021, the greatest Latin American academic event in the field of games and digital entertainment.

5 Conclusion

The manuscript describes the development and assessment of a mHealth nutrition education app to improve the food knowledge of adolescents. It was constructed in accordance with a person-based approach and evidence-based behavior change techniques. The app content was based on the Brazilian Dietary Guidelines that gained notoriety in the international media and scientific community. The Brazilian Dietary Guidelines are innovative as propose that healthy food choices should be qualitative, based on food processing extension, rather than quantitative, based on calories and nutrient content. It follows the NOVA food classification system. The gamification elements chosen led to the comprehension of the main learning contents. The mean story immersion score demonstrates the participant's involvement with the game's narrative.

This paper brings implications for practice and research. It describes all steps used for the app development, highlighting the theoretical benchmark of the stepwise approach method. Therefore, it can provide useful insights to public health researchers and nutrition educators that are planning to develop a mHealth nutrition education app from a practical perspective. In addition, it is a nutritional education tool that is attractive to its audience, accessible, and easy to use. Therefore, it can contribute to the quality of services provided by dieticians and nutritional educators.

Acknowledgements

Bruna Caroline Chaves Garcia has received a scholarship from CAPES (Finance code 001). This research was supported by the National Council for Scientific and Technological Development, Brazil (CNPQ), call notice n. 13/2017, grant n. #408441/2017-8.

Notes

This manuscript is an extended version of the short paper *"Efeitos do serious game Nutrigame - seu guia alimentar no conhecimento alimentar de adolescentes: um estudo piloto qualitativo de avaliação formativa", (Santos et al. 2021),* presented in the XX Brazilian Symposium of Digital Games and Entertainment - SBGames 2021.

References

Abarca-Gómez, L., Abdeen, Z. A., Hamid, Z. A., Abu-Rmeileh, N. M., Acosta-Cazares, B., Acuin, C., . . . Ezzati, M. (2017). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128·9 million children, adolescents, and adults. The Lancet, 390(10113), 2627-2642.

Alwashmi, M. F., Hawboldt, J., Davis, E., & Fetters, M. D. (2019). The Iterative Convergent Design for Mobile Health Usability Testing: Mixed Methods Approach. JMIR mHealth and uHealth., 7(4), e11656.

Amaral, E. M. G. R., Carvalho Silva Vargas, F., Santos Chagas, C. M., & Toral, N. (2017). Nutritional interventions for adolescents using information and communication technologies (ICTs): A systematic review. PLoS One., 12(9), e0184509.

Baranowski, T., Thompson, D., & Buday, R. (2012). Story Immersion of Videogames for Youth Health Promotion: A Review of Literature. Games for Health Journal., 1(3), 199-204.

Bardin, L. (2010). Análise de conteúdo (1977) (Vol. 70). Lisboa: Edições 70.

Belghali, M., Statsenko, Y., & Al-Za'abi, A. (2021). Improving Serious Games to Tackle Childhood Obesity. Frontiers in Psychology., 12(May), 657289.

Brasil. (2015). Dietary Guidelines for the Brazilian population (pp. 150 p.). Retrieved from https://bvsms.saude.gov.br/bvs/publicacoes/dietary_guidelines_brazilian_population.pdf

Brito, L. F., Ramos, R. A., Castro, J. F. B., Araújo, J., Ramos, R. P., & Leal, B. G. (2020). Nutrikids: jogo sério para o desenvolvimento do conhecimento nutricional em crianças e adolescentes. Revista Latinoamericana de Tecnología Educativa-RELATEC, 19(1), 93-106.

Brown, J. M., Savaglio, R., Watson, G., Kaplansky, A., LeSage, A., Hughes, J., . . . Arcand, J. (2020). Optimizing Child Nutrition Education With the Foodbot Factory Mobile Health App: Formative Evaluation and Analysis. JMIR Formative Research., 4(4), e15534.

Chagas, C. M. d. S., Pontes e Silva, T. B., Reffatti, L. M., Botelho, R. B. A., & Toral, N. (2018). Rango Cards, a digital game designed to promote a healthy diet: a randomized study protocol. BMC Public Health, 18(910), 1-10.

Chagas, C. M. S., Botelho, R. B. A., & Toral, N. (2018). Healthy eating through the eyes of adolescents: A qualitative analysis of messages from the Dietary Guidelines for the Brazilian Population. Revista de Nutrição, 31(6), 577-591.

Chagas, C. M. S., Melo, G. R., Botelho, R. B. A., & Toral, N. (2020). Effects of the Rango Cards game intervention on food consumption, nutritional knowledge and self-efficacy in the adoption of healthy eating practices of high school students: a cluster randomised controlled trial. Public Health Nutrition., 23(13), 2424-2433.

Charters, E. (2003). The use of think-aloud methods in qualitative research an introduction to think-aloud methods. Brock Education Journal, 12(2), 68-82.

Czajkowski, S. M., Powell, L. H., Adler, N., Naar-King, S., Reynolds, K. D., Hunter, C. M., . . . Charlson, M. E. (2015). From ideas to efficacy: The ORBIT model for developing behavioral treatments for chronic diseases. Health Psychology, 34(10), 971-982.

Dias, J. D., Domingues, A. N., Tibes, C. M., Zem-Mascarenhas, S. H., & Fonseca, L. M. M. (2018). Serious games as an educational strategy to control childhood obesity: a systematic literature review. Revista Latino-Americana de Enfermagem., 26, e3036.

Drywień, M., Górnicka, M., Kulik, S., & Górnicki, K. (2021). Patterns of Avoiding Nutrition Mistakes in Metropolitan Adolescents Are Associated with Sex, Nutrition Knowledge, Physical Activity, and Family Environment. Nutrients, 13(2), 1-13.

Ferdig, R. E. (2009). Handbook of research on effective electronic gaming in education (R. E. Ferdig Ed.). Hershey, Pennsylvania, USA: IGI global.

Fonseca, L. G., Bertolin, M. N. T., Gubert, M. B., & da Silva, E. F. (2019). Effects of a nutritional intervention using pictorial representations for promoting knowledge and practices of healthy eating among Brazilian adolescents. PLoS One., 14(3), e0213277.

Fossari, L. d. S. C., da Cruz, T. M. P., Mezadri, T., & Grillo, L. P. (2023). Desenvolvimento e validação de um serious game como ferramenta de educação de hábitos alimentares saudáveis em escolares. Revista Tecnologias Educacionais em Rede (ReTER), 4, 1-20.

Green, M. C., & Brock, T. C. (2000). The role of transportation in the persuasiveness of public narratives. Journal of Personality and Social Psychology., 79(5), 701-721.

IBGE. (2010). Pesquisa de orçamentos familiares, 2008-2009. Análise do consumo alimentar pessoal no Brasil. Rio de Janeiro: Ministério do Planejamento, Orçamento e Gestão, Instituto Brasileiro de Geografia e Estatística-IBGE.

Ivens, B. J., & Smith Edge, M. (2016). Translating the Dietary Guidelines to Promote Behavior Change: Perspectives from the Food and Nutrition Science Solutions Joint Task Force. Journal of the Academy of Nutrition and Dietetics., 116(10), 1697-1702.

Johnson, D., Deterding, S., Kuhn, K. A., Staneva, A., Stoyanov, S., & Hides, L. (2016). Gamification for health and wellbeing: A systematic review of the literature. Internet Interventions., 6(November), 89-106.

Lane, M. M., Davis, J. A., Beattie, S., Gómez-Donoso, C., Loughman, A., O'Neil, A., . . . Rocks, T. (2021). Ultraprocessed food and chronic noncommunicable diseases: A systematic review and meta-analysis of 43 observational studies. Obesity Reviews., 22(3), e13146.

Maramba, I., Chatterjee, A., & Newman, C. (2019). Methods of usability testing in the development of eHealth applications: A scoping review. International Journal of Medical Informatics., 126(June), 95-104.

Michie, S., Abraham, C., Whittington, C., McAteer, J., & Gupta, S. (2009). Effective techniques in healthy eating and physical activity interventions: a meta-regression. Health Psychology, 28(6), 690-701.

Michie, S., Richardson, M., Johnston, M., Abraham, C., Francis, J., Hardeman, W., . . . Wood, C. E. (2013). The behavior change technique taxonomy (v1) of 93 hierarchically clustered techniques: building an international consensus for the reporting of behavior change interventions. Annals of Behavioral Medicine, 46(1), 81-95.

Michie, S., Yardley, L., West, R., Patrick, K., & Greaves, F. (2017). Developing and Evaluating Digital Interventions to Promote Behavior Change in Health and Health Care: Recommendations Resulting From an International Workshop. Journal of Medical Internet Research., 19(6), e232.

Monteiro, C. A., Cannon, G., Levy, R., Moubarac, J.-C., Jaime, P., Martins, A. P., . . . Parra, D. (2016). NOVA. The star shines bright. World Nutrition, 7(1-3), 28-38.

Nielsen, J., & Landauer, T. K. (1993). A mathematical model of the finding of usability problems. Paper presented at the Proceedings of the INTERACT '93 and CHI '93 Conference on Human Factors in Computing Systems, Amsterdam, The Netherlands. https://doi.org/10.1145/169059.169166

Ribeiro, I. L., Filgueira, M. S. G., Ribeiro, I. L., Santa Rosa, J. G. d. S., & Costa, I. d. C. C. (2019). Serious game na promoção da saúde para escolares: uma pesquisa-ação de educação alimentar. Revista Baiana de Saúde Pública, 43(1), 132-150.

Santos, C. S., Garcia, B. C. C., Souza, L. A. M., Gomes, M. F., Fernandes, B. S., Esteves, E. A., & Rocha-Vieira, E. (2021). Efeitos do serious game Nutrigame - seu guia alimentar no conhecimento alimentar de adolescentes: um estudo piloto qualitativo de avaliação formativa. Paper presented at the XX Simpósio Brasileiro de Jogos e Entretenimento Digital.

Schmidt-Kraepelin, M., Thiebes, S., Tran, M. C., & Sunyaev, A. (2018). What's in the game? Developing a taxonomy of gamification concepts for health apps. Paper presented at the Proceedings of the 51st Hawaii International Conference on System Sciences.

Simmonds, M., Llewellyn, A., Owen, C., & Woolacott, N. (2016). Predicting adult obesity from childhood obesity: a systematic review and meta-analysis. Obesity Reviews., 17(2), 95-107.

Simons, D., De Bourdeaudhuij, I., Clarys, P., De Cocker, K., Vandelanotte, C., & Deforche, B. (2018). A Smartphone App to Promote an Active Lifestyle in Lower-Educated Working Young Adults: Development, Usability, Acceptability, and Feasibility Study. JMIR Mhealth and Uhealth., 6(2), e44.

Thompson, D., Baranowski, J., Buday, R., & Baranowski, T. (2012). Story Immersion in a Health Videogame for Childhood Obesity Prevention. Games for Health Journal., 1(1), 37-44.

Tsartsali, P. K., Thompson, J. L., & Jago, R. (2009). Increased knowledge predicts greater adherence to the

Mediterranean diet in Greek adolescents. Public Health Nutrition., 12(2), 208-213.

Vaitkeviciute, R., Ball, L. E., & Harris, N. (2015). The relationship between food literacy and dietary intake in adolescents: a systematic review. Public Health Nutrition., 18(4), 649-658.

Vidgen, H. A., & Gallegos, D. (2014). Defining food literacy and its components. Appetite, 76(May), 50-59.

Wang, J., Baranowski, T., Lau, P. W., Pitkethly, A. J., & Buday, R. (2015). Acceptability and Applicability of an American Health Videogame with Story for Childhood Obesity Prevention Among Hong Kong Chinese Children. Games for Health Journal., 4(6), 513-519.

Wang, J. J., Baranowski, T., Lau, P. W. C., Buday, R., & Gao, Y. (2017). Story Immersion May Be Effective in Promoting Diet and Physical Activity in Chinese Children. Journal of Nutrition Education and Behavior., 49(4), 321-329.e321.

Wheeler, A. (2013). Designing brand identity: an essential guide for the whole branding team (pp. 326).

Whittaker, R., Merry, S., Dorey, E., & Maddison, R. (2012). A development and evaluation process for mHealth interventions: examples from New Zealand. Journal of Health Communication., 17 (Suppl 1), 11-21.

WHO. (2016). Monitoring and evaluating digital health interventions: a practical guide to conducting research and assessment. Retrieved from https://www.who.int/publications/i/item/9789241511766

WHO. (2019). WHO guideline: recommendations on digital interventions for health system strengthening. Retrieved from https://www.who.int/publications/i/item/9789241550505

Yardley, L., Morrison, L., Bradbury, K., & Muller, I. (2015). The person-based approach to intervention development: application to digital health-related behavior change interventions. Journal of Medical Internet Research., 17(1), e30.