Augmented and Virtual Reality for Diet and Nutritional Education: A Systematic Literature Review

Enes Yigitbas
enes@mail.upb.de
Paderborn University
Paderborn, Germany

Janet Mazur
mazurj@mail.upb.de
Paderborn University
Paderborn, Germany

ABSTRACT

A healthy diet is becoming more difficult due to the increasing amount of processed foods, misinformation, or inadequate education about nutrition, which can lead to a variety of diseases in the long term. Supporting people with proper nutrition and diet education is therefore indispensable. As Augmented and Virtual Reality have become promising technologies for education, they are also becoming more common for diet and nutrition education and have been featured in several studies. Both technologies can display additional product information to the user or educate them through new learning applications to support healthy eating. As recent papers only address the use of AR or do not include current research findings, this paper provides a new systematic literature review with recent studies on AR/VR for nutrition and diet education. This paves the way for new research and approaches in this field and suggests future research directions. Overall, 41 out of 375 articles were extracted, categorized, and analyzed. The findings reveal that, especially for the nutritional education of children, AR games have a promising application. VR, on the other hand, is increasingly utilized for virtual supermarkets. The applications help users to better understand and memorize the educational materials about nutrition and expand their knowledge about their diet. In addition, the applications are usually easy to use and users want to continue using them in the future.

CCS CONCEPTS

• **Human-centered computing → Mixed / augmented reality**.

KEYWORDS

Augmented Reality, Virtual Reality, Nutrition Education, Diet Education

ACM Reference Format:
Enes Yigitbas and Janet Mazur. 2024. Augmented and Virtual Reality for Diet and Nutritional Education: A Systematic Literature Review. In *The PErvasive Technologies Related to Assistive Environments (PETRA) conference (PETRA '24), June 26–28, 2024, Crete, Greece.* ACM, New York, NY, USA, 10 pages. https://doi.org/10.1145/3652037.3652048

This work is licensed under a Creative Commons Attribution International 4.0 License.

PETRA '24, June 26–28, 2024, Crete, Greece
© 2024 Copyright held by the owner/author(s).
ACM ISBN 979-8-4007-1760-4/24/06
https://doi.org/10.1145/3652037.3652048

1 INTRODUCTION

A healthy and balanced diet is important for all people at any age to lead a healthy life. Therefore, the World Health Organization recommends eating various fruits, vegetables, whole grains and little sugar, salt, or unsaturated fats to support everyone on a healthy diet [47].

However, studies have shown that due to the increasing availability of processed foods such as fast food [1, 42] or insufficient education about a healthy diet [63], it is becoming more and more difficult to integrate and apply it in one's own life. This is because processed foods contain a high amount of calories, saturated and trans fats, sugar or salt and thus lead to plentiful diseases such as malnutrition, obesity, and overweight or diabetes [1, 42]. In addition, it is challenging to select from the overabundance of food those that are healthy and distinguish between correct and incorrect dietary and nutrition information, which results in various misconceptions [13, 14]. Nutrition education is especially indispensable for people with special dietary needs like diabetes as knowledge about ingredients, skills for measuring blood glucose, or settings for integrating the disease into everyday life are needed [11].

To solve this concern, it is essential to educate people with the proper knowledge about diet and nutrition as knowledge and eating behavior are influenced by various factors like social status, community, media, and education in childhood [10, 55, 59]. One promising idea in this context is to use Augmented Reality (AR) and Virtual Reality (VR) to support people in healthy eating and to improve their knowledge. Applications for this have already been developed. For example, mobile applications have been designed to provide users with helpful product information regarding ingredients [17], or virtual cafeterias that can create an unbiased environment to teach about healthy eating [30].

AR and VR have been a promising topic in research in recent years. While VR immerses the user in a virtual world, AR overlays digital objects into the real world. Particularly, the increase in the supply of hardware for consumers and the simplification of development with the help of Software Development Kits (SDK) led to an increasing usage of both technologies. Thoroughly, the interest in the applications in education has increased strongly in recent years, as it motivates students to discover the material from different perspectives [36] or it enables practicing and learning of medical training [7] or surgeries [48]. One advantage is that most applications are accessible through mobile devices and can therefore be installed and applied by the majority of people on their end devices. VR on the other side has been proven useful for the treatment of various mental disorders, such as anxiety disorders [50] or post-traumatic stress disorder [16], as it can create realistic, safe, and controllable diagnostic and learning environments [27].

In addition, VR can also be used for education, for example, in Virtual labs, where students are allowed to conduct and experience chemical or physical experiments in a safe environment [61].

As AR and VR both have great educational value, each technology has been increasingly applied in the field of diet and nutrition education [11, 30]. Using these technologies, it may be possible to better educate or motivate people of all ages regarding healthy eating [17, 51]. To analyze the existing scientific research in this area, a few literature reviews have already been published on this topic, but mostly focused on the use of AR for nutrition education [53] or do not contain the latest research [20] and thus do not provide a current overview of the usage of AR and VR. However, as such applications have been developed and proposed by researchers frequently in the past years, a new systematic literature review is demanded to analyze the current state-of-the-art of AR and VR in nutrition and diet education and present an outline of future research directions. For the systematic literature review, the following research questions have been defined:

- **RQ 1:** How can AR and VR be utilized for nutrition and diet education?
- **RQ 2:** What are the advantages and disadvantages of AR and VR for Education in Nutrition and Diet?
- **RQ 3:** What future research work is needed to apply AR and VR to Nutrition and Diet Education?

As AR and VR both cover various use cases in nutrition and diet education, **RQ 1** focuses on the usage and the technology. **RQ 2** presents a summary of the study results from the research found and answers the demand for these technologies and applications followed by **RQ 3** highlighting what future work is still needed in this field.

The following Section 2 outlines briefly the current literature reviews for nutrition education with AR or VR. Afterward, Section 3 describes the methods of this systematic literature review. The main Section 4 of this paper subsequently presents the results of the search and describes the studies that were found. Section 5 then deals with answering each of the research questions. In the end, Section 6 concludes with a summary of the results of this paper and the needed future work.

2 RELATED WORK

Augmented Reality (AR) and Virtual Reality (VR) have been a topic of intense research in the last decades. While VR interfaces support the interaction in an immersive computer-generated 3D world and have been used in different application domains such as training [69], education [72], modeling [66], software engineering [73], or healthcare [70], AR enables the augmentation of real-world physical objects with virtual elements and has been also applied in various application domains such as product configuration (e.g.,[24], [25]), prototyping [32], planning and measurements [71], robot programming (e.g., [39], [67]), or for realizing smart interfaces (e.g., [38], [68]).

In the following, we especially focus on existing approaches that primarily use AR and VR for nutrition and diet education. Since AR and VR have already been promisingly applied in this field and therefore presented by others in a literature review, these studies will be presented in the following to outline why this work differs and why a new and revised systematic literature review is necessary.

Saboia et al. [53] conducted a literature review on the use of AR in nutrition education and evaluated studies between 2012 and 2017. They outlined research approaches, methods and use cases like education, shopping, and diets or eating disorder therapies.

Paramita et al. [49] performed a study on AR for nutrition education using findings between 2010 and 2019. Study methods and effects on the user by applying AR in nutrition education were mainly analyzed.

Ferrer-Garcia et al. [22] reviewed studies on VR for eating disorders and obesity therapy. They categorized studies from 1986 to 2012 regarding the study design and treated disease.

McGuirt et al. [20] performed a comprehensive scoping review of the use of Mixed Reality (MR) technologies in nutrition education and behavior change. Here, they collected and analyzed survey data from 92 studies from 2009 to 2018 with the help of REDCap (Research Electronic Data Capture). The focus was on Mixed Reality (MR) technology and use cases, study objectives, outcomes, and user impact. They defined six research focuses for MR: nutrition education, behavior change, consumer preferences, product testing, concept paper, and others.

In contrast to the aforementioned works, this paper describes and classifies both AR and VR applications for nutrition education. Since some of the previously mentioned papers only deal with AR or VR or only include older studies, a new systematic literature review is necessary. Our work contributes to a systematic and comprehensive view of the current approaches that AR or VR apply to nutrition and diet education.

3 METHODOLOGY

This section outlines how the scientific search process regarding AR and VR for diet and nutritional education was conducted and which data was considered, followed by data analysis. To answer the research questions defined in Section 1, this study was conducted as a systematic literature review based on Kitchenham's original guidelines [37].

As research using AR and VR in nutrition and diet education only began in the early 2000s, no additional time limit was applied to the literature review.

A manual literature search, illustrated in Figure 1, was performed using the databases Science Direct, Google Scholar, PubMed, and IEEE Explore. The search was narrowed down using the keywords *Augmented Reality*, *Virtual Reality*, *Nutrition Education*, and *Diet Education*. This yielded the following results for the search terms: *AR AND nutrition education* (965 results), *AR AND diet education* (20 results), *VR AND nutrition education* (2,215), and *VR AND diet education* (70 results). A total of 60 results were found on IEEE Explore, 79 results on PubMed, 109 results on Science Direct, and 3,022 results using Google Scholar. However, in all databases, many irrelevant results were found within the search. Since most databases provided manageable results, all articles outside of Google Scholar were initially considered further. On Google Scholar, on the other hand, the results after the 5th or 6th page were no longer relevant, so they were not reviewed further. After removing duplicates, all 369 articles were scanned based on title and abstract, and any that did not discuss AR or VR in the context of diet or nutrition education were removed. Subsequently, the articles found were then examined more closely for their content. Articles containing a literature review were filtered out, and studies on VR that were more concerned with treating diseases such as eating disorders and obesity were removed, as the focus of this review was on nutrition education. Studies that were not in English were also not considered further. In addition, publications that used neither AR nor VR were excluded. The result is 41 studies from the last 20 years.

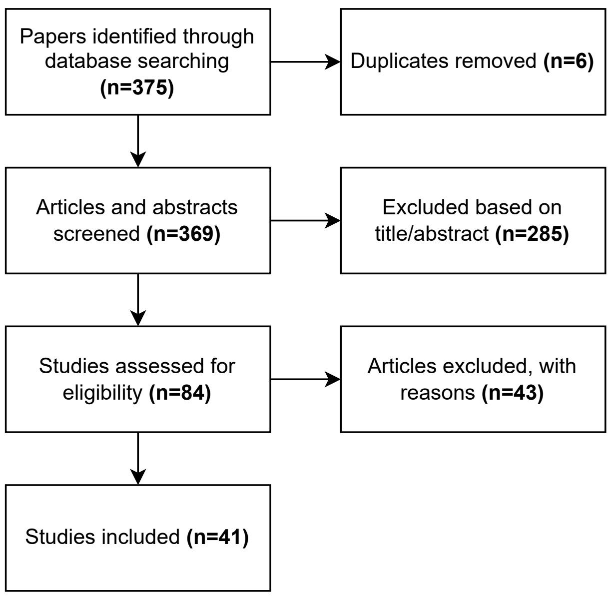

Figure 1: Literature search and selection process

The articles obtained were then summarized and analyzed using a table calculation program. The following data were extracted for each study:

- Basic data such as title, authors, and year of publication.
- The technology used.
- The methods of the study such as the research approaches, data collection, and analysis methods.
- Content analysis of AR/VR for nutrition and diet education.
- Results of the study.
- Study limitations and future Work

4 RESULTS

This section presents the results found through the literature review. A simplification of the study data can be found in Table 1.

The content analysis of AR and VR for nutrition and diet education revealed that these technologies are used in various applications, with VR being used differently for nutrition education. Therefore, the studies found were divided into 5 use cases to further answer **RQ 1**. The use cases were divided into *Nutrition Education*, *Nutrition Information*, *Grocery Shopping*, and *Portion Size Estimation*. Nutrition education and information were considered separate use cases, as some studies focus on informing users about nutrition and food ingredients rather than providing educational information. Of course, even just showing nutritional information will have an educational benefit for the user in the end, but the approaches are different. Grocery shopping was also considered a separate use case, as it focuses on healthy grocery purchasing. Some studies focus on helping people learn the right portion size, while others, such as weight management education and AR-based food size changes, are not commonly found. Furthermore, some studies refer to two use cases. These studies were classified into the use case that was most clearly addressed. In addition, the studies are classified into two use cases and analyzed based on their study design, including experimental, system development, presentation, single group pre- and post-test, and controlled trials. Some studies, like interviews, cannot be classified clearly into one category. At the end of the data collection, additional statistics describing the technology used in the studies and the study objectives were created for the analysis to further examine **RQ 1**.

When looking at the technologies used, it becomes apparent that AR is used much more often in the context of nutrition and diet education than VR, see Figure 2. 27 studies use AR applications, primarily mobile applications for smartphones or tablets, for ease of use and accessibility. These applications provide additional nutrition information and can be used at any time, such as shopping for groceries. Only 4 use head-mounted displays, allowing for product information display or food size changes to influence eating behavior. The remaining 14 studies use VR for nutrition and diet education, enabling neutral environments like virtual cafeterias or supermarkets. These applications help explore eating and shopping behavior. In the following, the individual application areas of AR and VR are explained in more detail to provide an overview of the individual results of the research work.

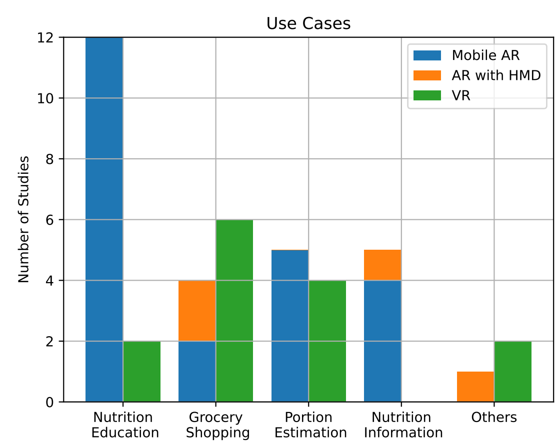

Figure 2: Use cases with the technology involved

4.1 Nutrition Education

The majority of research focuses on food shopping support and exploration or nutrition education, see Figure 2. Twelve approaches use AR [5, 11, 13, 17, 19, 23, 34, 51, 56, 64, 65, 74] whereas just two applications found use VR [6, 35]. In mobile AR applications for

			Technology		Use Cases					Study Design				
No.	Publication	Year	AR	VR	Nutrition Education	Nutrition Information	Grocery Shopping	Portion Size Estimation	Others	Experimental Study	System Development	Single Group Pre-Post	Controlled Trial	Others
1	Ahn et al. [2]	2015	•				•					•		
2	Alanaís et al. [3]	2023		•			•			•	•			
3	Alhamdan et al. [4]	2020	•				•				•			
4	Alshebil et al. [5]	2023	•		•								•	
5	Bayu et al. [45]	2013	•			•					•			
6	Blitstein et al. [9]	2020		•			•			•				
7	Brown et al. [6]	2005		•	•					•				
8	Calle-Bustos et al. [11]	2017	•		•				•					
9	Chandak et al. [12]	2022		•			•			•	•			
10	ChanLin et al. [13]	2018	•		•				•			•		
11	Domhardt et al. [17]	2015	•		•			•		•				
12	Eichhorn et al. [18]	2021		•			•			•				
13	Escárcega-Centeno et al. [19]	2015	•		•						•			
14	Fernandez et al. [21]	2013		•			•				•			
15	Franco-Arellano et al. [23]	2024	•		•					•	•			
16	Gutiérrez et al. [26]	2017	•				•			•				
17	Hariadi et al. [28]	2015	•			•					•			
18	Ho et al. [29]	2022		•				•		•				
19	Isgin-Atici et al. [30]	2020		•				•		•				
20	Jiang et. al [31]	2018	•			•	•				•			
21	Juan et. al [33]	2019	•			•						•		
22	Kalimuthu et. al [34]	2023	•		•					•	•			
23	Karkar [35]	2018		•	•								•	
24	Kulpy et al. [40]	2017	•			•				•				
25	Lam et al. [44]	2020	•					•					•	
26	LeRouge et al. [41]	2015		•					•	•	•			
27	Lin et al. [65]	2023	•		•					•	•			
28	Mellos et al. [43]	2022	•					•					•	
29	Narumi et al. [46]	2012	•						•	•				
30	Reisinho et al. [51]	2021	•		•					•	•			
31	Rollo et al. [52]	2017	•					•					•	
32	Ruppert [8]	2013		•	•		•							•
33	Sajjadi et al. [54]	2022		•	•			•			•	•		
34	Sonderegger et al. [56]	2019	•		•								•	
35	Stütz et al. [57]	2014	•					•		•	•			
36	Sullivan et al. [58]	2013		•					•					•
37	Tanno et al. [60]	2018	•					•			•			
38	Waltner et al. [62]	2015	•			•	•				•			
39	Wu et al. [64]	2022	•		•					•	•			
40	Yulia et al. [74]	2018	•		•	•								•
41	Zhang et al. [75]	2011		•				•			•			

Table 1: Systematic review studies

nutrition education, the food is first scanned and recorded using a smartphone or tablet. The food is identified along with additional details such as its fat or calorie content. It is possible to personalize the information, particularly for people with diabetes. The user's understanding of different foods is increased as they examine the data and identify which elements are healthy. Figure 3 is an example of one way the information could be presented.

ChanLin et al. [13] implemented such an application and conducted a study on 65 college students, revealing that most learned nutrition through media, family, and friends, leading to misconceptions. They used a mobile AR application to monitor nutrient intake and learn about nutrition. Post-test results showed improved knowledge and decreased misconceptions. However, further studies are required to substantiate the results. Escárcega-Centenoa et al. [19] also developed a mobile AR application to educate about food ingredients with a focus on sugared beverages. In the future, this application still needs to be tested in studies and the learning behavior analyzed.

Figure 3: AR prototype showing a) Recommendations b) Health Impact Prediction and c) Nutritional Information, by [26]

Another way to use AR for nutrition education is to provide educational videos and additionally display nutrition information. Yulia et al. [74] developed a mobile AR application for nutrition education, focusing on traditional Sudanese food preparation. The application was tested with teenagers, who found it enjoyable and interested in continuing to use it. The study suggests that AR can be a valuable tool for nutrition education.

It is often easier for children in particular to learn through playing. For this reason, Reishino et al. [51], Wu et al. [64] and Lin et al. [65] developed mobile AR games to support children in nutrition education and tested the games with children. Reisinho's "FlavorGame" [51] combines a board game with an AR application to teach children about cooking. The experimental study showed positive results: Participants were positive about using AR for cooking simulations. However, some children had technical difficulties, such as holding the camera still or pointing the smartphone at the game cards. Kalimuthu et al. [34] developed a similar application for adolescents. Franco-Arellano et al. [23] extended an existing nutrition education application with AR mini-games and found it

Figure 4: Virtual environment for choosing a healthy breakfast from [35]

to be easy to use and engaging. However, technical limitations such as limited processing power and small screen size were identified.

Nutrition education for children can also be implemented with VR games, as Karkar et al. [35] show. An immersive VR environment was developed for this purpose, as shown in Figure 4. The virtual space shows a dining area with healthy and unhealthy foods for breakfast, with nutritional information on the walls. Users can interact with the food using an HMD and receive immediate feedback. A controlled study with 29 schoolchildren showed that the VR system improved learning performance compared to conventional methods and increased interest in the subject.

Generally, one can say that especially in nutrition education for children with AR/VR, gamification can be recognized to increase user knowledge, engagement, and experience.

Some studies have examined nutrition education for individuals with special needs or health conditions, such as diabetes or HIV-positive women. The study by Brown et al. [6] found that women found the VR application educational and user-friendly. Calle-Bustos et al. [11] developed a mobile AR game for children with diabetes to help them make carbohydrate choices. The game shows virtual food on real plates allowing users to view and analyze the food from any position. Users choose from three food groups and have to assign the food to the correct carbohydrate category. A pre- and post-test study with 70 children aged 5 to 14 years showed the AR game improved their knowledge of carbohydrate choices and was easy to use. However, the effectiveness of AR on learning outcomes is unclear. Domhardt et al. [17] developed a mobile AR app that helps people with diabetes to assess carbohydrates and is integrated into a diabetes diary. The technology from Stütz et al. [57] was used for this application, which was tested with six participants of different ages. Older participants had difficulties with smartphone interaction [17]. Carbohydrate tracking improved blood glucose estimation, suggesting the use of AR for diabetes education. A study by Alshebil et al.[5] revealed that patients with type 1 diabetes, regardless of gender and age, gained more knowledge with an AR application than with traditional teaching methods such as brochures and written material about the food groups and basic carbohydrate counting. The mobile AR application ran on a tablet and showed a doctor character educating the user about carbohydrate counting when the camera was pointed at a plate or packaged food.

4.2 Nutrition Information

Since some studies have focused less on the specific education of nutritional knowledge and more on the provision of nutritional information that helps users eat healthily, this area is considered separately. There are no applications with VR for this use case. All five applications used AR [28, 33, 40, 45] with one application utilizing a HMD [31]. Mobile AR applications were developed to help users correctly interpret nutrition labels on packaged foods. Studies by Sonderegger et al. [56] and Juan et al. [33] have shown that these applications can significantly improve knowledge about carbohydrate choices. To this end, an AR application was developed and tested in a pre- and post-test study with 40 participants [33]. The participants were satisfied with the application and found it easy to use. However, the representativeness of the study is limited to participants from higher education, so further research with a wider variety of participants is needed. Participant feedback also indicated that it would be beneficial to analyze more products with the application and to expand the information to include more nutritional information or diet-related diseases. Sonderegger et al. [56] prove similar results with the additional remark that further and especially long-term studies are necessary to analyze the effects of AR on nutrition education.

Kulpy et al. [40] developed *Fruitify*, a mobile AR application that uses Unity3D and Vuforia SDK to display nutritional information for fruits. The application uses markerless AR technology to recognize fruits and display vitamins, minerals, and calories. It also allows users to track and analyze their diet. In an experimental study with 20 users, the application was found to be user-friendly but was criticized for difficulties in recognizing fruits with smooth surfaces, lighting conditions, and resource-intensive image processing. Users had to enter the weight of the fruit in grams, which often led to inaccurate nutritional information. Future improvements include portion size estimation for smooth surfaces with poor lighting conditions and improved resource utilization.

However, nutritional information can be displayed not only on fruit but also on all other foods. This has been addressed by Hariadi et al. [28] and Bayu et al. [45] who both developed mobile applications to identify the food and display the correct information about the ingredients using object and image recognition. The study outcomes show that 92% of the foods were accurately recognized and, on average, the names and nutrients were provided within 9,295 seconds [28].

A similar application was developed by Jiang et al. [31], which uses Google Glasses to display nutritional information while purchasing or eating food. Their system implements reverse image search (RIS) and text mining to recognize the food and retrieve nutritional information from a database. The system was evaluated for recognition accuracy, speed, tracking stability, and jitter. Among other things, their results show an accuracy of 75.9% in recognizing real food, but they mainly had problems recognizing different types of meat.

4.3 Grocery Shopping

AR and VR are also applied in grocery shopping for support and analysis. Most of the applications are in VR [3, 8, 9, 12, 18, 21], two applications use mobile AR [2, 62] and two more AR with A HMD [4, 26]. AR applications can scan products to obtain nutritional information, make personalized suggestions in real-time, and raise awareness of unhealthy products. Applications like Ahn et al. [2] offer recommendations for allergies, diets, and unhealthy diets. AR tags also help with navigation through the store and show the location of recommended products or products to avoid. User positioning is image-based, using a picture of the nearest food item to create a tag. A pedometry algorithm matches the user's location with the database. AR product tags are displayed on the user interface, which can be filtered according to individual needs. A pre- and post-study with 15 participants showed that the AR tags reduce the time needed to search for healthy food by two to three times.

Waltner et al. [62] and Gutíerrez et al. [26] conducted similar studies, demonstrating the usefulness and ease of using an application. However, more extensive tests with more products, more precise suggestions, and more participants are needed [26]. Alhamdan et al. [4] developed an AR application using an HMD for personalized grocery shopping. The system uses Convolutional Neural Networks (CNN) trained with supermarket videos to create a database and recognize objects. The system includes a recognition agent, a nutrition agent that helps the user interpret the ingredients correctly, and a health agent that has access to the user's medical report and can alert the user to products he or she should not consume and suggest healthy alternatives. The system requires smart glasses to display information in real-time. Tests have shown high accuracy in recognizing food items and successful data analysis, but no studies have been conducted with participants yet.

Apart from that, virtual supermarkets can be applied to educate about nutrition during grocery shopping or to analyze shopping behavior by providing a unified simulation environment and a simple representative environment to increase understanding of how contextual factors influence consumers [9]. Such virtual supermarkets have been developed, for example, by Fernandez et al. [21], Blitstein et al. [9], Alanís et al. [3] or Eichhorn et al. [18]. An example of this can be found in Figure 5.

Blitstein et al. [9] used the virtual supermarket to investigate how front-of-pack nutritional labeling influences food purchases by low-income parents. Using the virtual supermarket, they could show that even simple nutrition labels can help parents make healthy purchasing decisions. Chandak et al. [12] developed a VR game that immerses users in a virtual supermarket game, with two parts. In the first round, no additional information is displayed, while in the second round, all necessary information and warnings about high sugar or carbohydrate content are displayed. A user study with 29 participants found that adding additional information led to healthier food choices. However, it's unclear whether the learning success is permanent, as better food choices are more intuitive when more product information is available.

Ruppert [8] interviewed Mr. Burke from Indiana University Bloomington and Ms. Jones from the University of Utah College of

Figure 5: Virtual Supermarket with a shopping list in the upper right corner by [9]

Health about the use of VR technologies in obesity and diabetes research. They discussed how eye tracking or electroencephalography to measure brain activity can be integrated into virtual supermarket simulations to analyze shopping behavior. Ms. Jones tested her virtual supermarket with students and observed that regular visits improved their understanding of nutritional information and purchasing behavior, potentially improving physical health.

4.4 Portion Size Estimation

Many studies have also looked at portion size or calorie estimation to help properly estimate the portions of food and the nutrients they contain. Thereby five studies found use AR [43, 44, 52, 57, 60] and four use VR [29, 30, 54, 75].

Stütz et al. [57] implemented two approaches in a mobile AR application to assist users in portion estimation and ingredient determination. The first uses 3D points and a 3D shape approximation, while in the second the nutrient content is approximated by using a ruler. An experimental study with 28 subjects demonstrated the application significantly helps users estimate portions and is easy to use. Here, the approach using 3D shapes was more accurate than the second approach. However, further analyses are required for other types of food and complex dishes.

A similar system was developed by Zhang et al. [75], Mellos et al. [43] or Lam et al. [44]. Lam et al. [44] conducted a controlled study of 36 adults with and without a health science background. The results showed that the application had a good System Usability Scale (SUS) level of 76, but feedback from the study participants indicated that the user interface could be improved in terms of design and smoothness. While estimating food portions, 22.5% in the non-health science group and 26.6% in the group with health sciences correctly estimated sizes using the application. Overall, the portion size was overestimated, however.

A different approach to determining portion size was taken by Tanno et al. [60] who developed a mobile AR application with the Apple ARKit framework that uses CNN. Here, after taking a photo, the food and its world coordinates are detected using CNN. The area is directly calculated using AR. As this is a 2D quantity, the calorie percentage is then estimated using a quadratic curve. This improves the accuracy of the calorie estimate.

Rollo et al. [52] developed a mobile AR application to assist in proper food portioning. A controlled study showed the tool was easy to use and had the potential for optimal portion size. However, it was difficult to see the real amount of food already served under the virtually displayed food, and especially with white food, the contrast to the white plate was too low. The application should be tested with more dishes in the future.

VR can help users estimate portion sizes by providing virtual cafeterias that display different food and beverage models. An experimental study by Isgin et al. [30] revealed that their system was easy to use and efficient for nutrition education, especially with younger people. However, it did not support other senses like smell or touch, and adaptations were needed for people with physical disabilities and visual-induced motion sickness [30]. Similar results were shown in the studies by Sajjadi et al. [54] and Ho et al. [29] who evaluated virtual environments for portion sizing. In the experimental studies, it was shown that virtual learning improves the identification of food and the estimation of portions [29, 54]. Still, further studies with more participants and foods are necessary to draw representative conclusions [29, 54].

4.5 Others

A few studies were also found, which addressed other topics for nutrition and diet education. Here, two studies utilize VR [41, 58] and one uses an AR application with HMD [46]. Since the feeling of satiety depends not only on the actual amount eaten but also on external factors, Narumi et al. [46] designed an AR application that changes the perception of food by magnifying it to influence the feeling of satiety and food intake. An experimental study with 12 participants showed the system could control food intake and satiety perception. However, the size of food was only adjustable when held by hand or cutlery, and the long-term effects remain unclear.

VR can also aid weight management through an application developed by LeRouge et al. [41], which uses virtual avatars and coaches. The application motivates a healthy lifestyle and allows users to interact with personalized health coaches at any time and from anywhere. An experimental study showed that the test subjects enjoyed the interaction.

In the comparative study by Sullivan et al. [58], using the VR application *Second Life*, it was shown that patients with VR were able to maintain their weight more easily, but patients with personal treatment reduced their weight more. Results suggest that by spending more time at *Second Life*, participants learned more about how healthy dieting could make long-term changes in their behaviors, and maintain anonymity, despite the lack of travel or cost.

5 DISCUSSION

This section discusses the answers to the research questions raised in Section 1 based on the results found through the systematic literature research.

5.1 RQ 1: How can AR and VR be utilized for nutrition and diet education?

Both AR and VR can be applied to education in nutrition or diets. AR is often deployed in the form of mobile applications, as they can be used by various people and in any location. The Unity and Vuforia development environments are often used to develop applications that can recognize objects such as food packaging, fruit, or food with the help of the smartphone camera to display additional information about nutritional content. This can assist users in assessing foods and correctly interpreting nutritional information. Special focus can be placed on diabetic patients, who have to pay particular attention to their diet, and it can also offer them help in tracking their eating habits. To teach children about healthy nutrition, AR games can be introduced to learn about nutrition and healthy food playfully. Of course, VR games can also be used for children's education.

Another area of application is grocery shopping. With the help of AR, the user can be provided with additional important information while shopping or be made aware of healthier alternatives to support a healthy diet. The information can also be personalized and address individual dietary needs, such as daily nutritional requirements or allergies.

Virtual supermarkets offer a realistic environment for scientists to analyze purchasing behavior, helping people eat healthily in the long term. They provide product information and support purchase decisions. Regular visits to virtual supermarkets can improve long-term purchasing behavior. Mobile AR systems and virtual environments can help estimate ingredients and portion sizes, with camera recording aiding in estimating the ingredients of the dishes and food volume calculation. Users can interact with virtual cafeterias to compare portion sizes.

Other uses of AR are estimation, meal size modification, and weight loss control. By increasing meal size and reducing food consumption, users can feel more satisfied and manage their weight. Virtual environments with nutrition information and virtual agents can also aid in weight loss.

5.2 RQ 2: What are the advantages and disadvantages of AR and VR for education in nutrition and diet?

The advantages of mobile AR applications for nutrition and dietetics education are that they can be easily accessed through a smartphone or tablet, so numerous people can be reached through these applications. In addition, most users in the studies perceived the AR and VR applications as easy to handle and utilize and would continue to use them in the future. In particular, games for children and young people were found to be fun and interesting, and they enjoyed learning with the applications.

Through the studies, it was shown that the AR and VR applications helped participants improve their knowledge regarding nutrition and diet so that by simply providing information, misinterpretations, and misconceptions can be reduced and healthier eating decisions can be made. They also aid in estimating portion sizes, calorie ratios, and food volume, thereby improving diet monitoring and assessment. Furthermore, these applications can help reduce weight and maintain it over time, thereby promoting healthier eating habits.

Virtual supermarkets can be utilized to change purchasing behavior and thus reduce the time spent shopping. In parallel, they enable the scientific analysis of purchases to develop further aids for learning healthy purchasing behavior.

The disadvantages of AR and VR, or the limitations of the studies found, nevertheless, are that these are often only pilot studies with a small number of participants. This means that learning successes can only be demonstrated in a small number of people and are not representative of the wider population, as they also only take into account a specific population group such as members of a university or children. In this context, it should be noted that the studies were all conducted in different countries and, despite different cultures, yielded similar results. Another disadvantage of the studies is that they were mostly carried out over a short period and no long-term effects on nutrition education have been demonstrated. In addition, the studies were often conducted with only one group and no control group, and thus it was not analyzed whether education with AR and VR provides better learning outcomes for nutrition compared to conventional methods.

The technologies can be challenging for some users, including elderly people, who have little experience in using smartphones, children, who find it difficult to hold the smartphone in their hands for a longer period without covering the camera, and those with physical disabilities or motion sickness. Additionally, there are technical limitations such as computationally intensive applications which can be problematic for some smartphones and head-mounted devices such as Hololens. Furthermore, HMDs are still not widespread, so smartphone applications are currently more suitable for the majority of users.

Since other senses such as smell, taste or texture are also essential in learning healthy cooking, it is also a disadvantage that these senses are not yet addressed by AR or VR applications.

5.3 RQ 3: What future research work is needed to apply AR and VR to nutrition and diet education?

Regarding the previously described disadvantages of the use of VR and AR, more research will be needed in the future for education in nutrition and diet. During the systematic literature review, the following six research challenges were extracted that require further consideration in the future:

(1) **Larger and long-term studies:** For one, the studies need to be applied to larger participants and populations, and the results need to be compared to traditional teaching methods. It should therefore be determined in more detail which concrete applications lead to the learning process being improved and what the long-term learning achievements are. This is for example needed in nutrition education for children or people with special needs.
(2) **Improved product data and databases:** More product data are needed to provide additional information on more foods regarding their ingredients, or more product information could be shown in general and not just focus on a few ingredients. In addition, the studies should be conducted with more foods to provide more meaningful results.

(3) **Improved food recognition:** The recognition processes should be improved to recognize the foods faster, more accurately, and reliably or to determine their size. This should be developed especially for those foods that are more difficult to detect due to their surface or shape such as fruits or meat. This challenge mainly needs to be faced in nutrition information applications where additional information is displayed next to the food for example during grocery shopping or for portion size estimation applications.

(4) **Limited processing power:** Since image recognition, in particular, is computationally intensive, and the applications run on mobile devices or HMDs with limited computing capacity, it is necessary to improve the algorithms or accelerate them.

(5) **Data privacy and security:** Concerning technologies, data privacy and security is still an open issue that needs to be considered in the future as it is not yet addressed. Most applications use and collect a lot of personal and sensitive health data of the users, which offers a target for data leakage.

(6) **Sustainable nutrition education:** The approaches found do not yet include any education regarding sustainable nutrition. As food, in particular, is responsible for over a third of human-made greenhouse emissions [15], it is necessary to adapt eating habits sustainably and educate people about this, because of climate change. For example, plant-based alternatives could be provided during grocery shopping or suggestions for reducing meat consumption.

6 SUMMARY AND FUTURE WORK

This paper reviews and analyzes recent studies on nutrition and diet education using AR and VR. The results show that AR and VR can enhance knowledge and change behavior by providing more information about product ingredients and their meanings. The research shows that users perceive AR and VR as helpful and easy to use, leading to improved knowledge about their diet and healthier eating habits. Nevertheless, future research is still needed to study the effects with long-term studies and with a larger number of subjects and to compare them with traditional teaching methods. Additionally, user interfaces and food recognition need to be optimized for more accurate product detection.

REFERENCES

[1] Mohammadbeigi A, Asgarian A, Moshir E, Heidari H, Afrashteh S, and Khazaei S. 2018. Fast food consumption and overweight/obesity prevalence in students and its association with general and abdominal obesity. *Journal of preventive medicine and hygiene* 59, 3 (Sep 2018), E236–E240.

[2] Junho Ahn, James Williamson, Mike Gartrell, Richard Han, Qin Lv, and Shivakant Mishra. 2015. Supporting Healthy Grocery Shopping via Mobile Augmented Reality. *ACM Trans. Multimedia Comput. Commun. Appl.* 12, 1s, Article 16 (oct 2015), 24 pages.

[3] Pamela Inés Marroquín Alanís, Rocío Elizabeth Cortez Márquez, Daniel Cantú Gonzalez, Ana Gabriela Rodríguez Mendoza, and Daniel Muñoz. 2023. Analysis of the Impact of Virtual Reality on High School Students' Learning in Nutrition Courses. In *2023 Future of Educational Innovation-Workshop Series Data in Action.* IEEE, Monterrey, Mexico, 1–6.

[4] Yasmeen Alhamdan, Saif Alabachi, and Naimul Khan. 2020. Extended Abstract: CoShopper - Leveraging Artificial Intelligence for an Enhanced Augmented Reality Grocery Shopping Experience. In *AIVR.* Utrecht, Netherlands, 337–338.

[5] Norh Alshebil, Kulud Alkadi, Nagarajkumar Yenugadhati, and Mohammed Al Dubayee. 2023. Using Augmented Reality to improve Nutritional Educational for Type 1 Diabetic Children and Adolescents: Quantitative study of Patient Knowledge Retention. In *2023 20th Learning and Technology Conference (L&T).* IEEE, Jeddah, Saudi Arabia, 32–36.

[6] Sarah B, David Nunez, and Edwin Blake. 2005. Using Virtual Reality to Provide Nutritional Support to HIV+ Women. In *The 8th Int. Workshop on Presence — Presence 2005.* University College London – Department of Computer Science, London, England, 319–323.

[7] Yahia Baashar, Gamal Alkawsi, Wan Nooraishya Wan Ahmad, Hitham Alhussian, Ayed Alwadain, Luiz Fernando Capretz, Areej Babiker, and Adnan Alghail. 2022. Effectiveness of Using Augmented Reality for Training in the Medical Professions: Meta-analysis. *JMIR Serious Games* 10, 3 (5 Jul 2022), e32715.

[8] Ruppert Barb. 2011. New Directions in the Use of Virtual Reality for Food Shopping: Marketing and Education Perspectives. *Journal of diabetes science and technology* 5 (03 2011), 315–318.

[9] Jonathan L. Blitstein, Joanne F. Guthrie, and Caroline Rains. 2020. Low-Income Parents' Use of Front-of-Package Nutrition Labels in a Virtual Supermarket. *Journal of Nutrition Education and Behavior* 52, 9 (2020), 850–858.

[10] Bittar C. and Soares A. 2020. Media and eating behavior in adolescence. *Cadernos Brasileiros de Terapia Ocupacional* 28 (2020), 291–308.

[11] Andrés-Marcelo Calle-Bustos, M.-Carmen Juan, Inmaculada García, and Francisco Abad. 2017. An augmented reality game to support therapeutic education for children with diabetes. *PLOS ONE* 12 (09 2017), e0184645.

[12] Abhimanyu Chandak, Ashutosh Singh, Shubham Mishra, and Sarishty Gupta. 2022. Virtual Bazar-An Interactive Virtual Reality Store to Support Healthier Food Choices. In *1st Int. Conf. on Informatics (ICI).* IEEE, Noida, India, 137–142.

[13] Lih-Juan ChanLin, Kung-Chi Chan, and Chiao-Ru Wang. 2019. An epistemological assessment of learning nutritional information with augmented reality. *The Electronic Library* 37 (04 2019).

[14] Graeme Clugston and Trudy Smith. 2002. Global nutrition problems and novel foods. *Asia Pacific Journal of Clinical Nutrition* 11 (10 2002), S100 – S111.

[15] M. Crippa, E. Solazzo, D. Guizzardi, F. Monforti-Ferrario, and A. Leip. 2021. Food systems are responsible for a third of global anthropogenic GHG emissions. *Nat Food* 2 (2021), 198–209.

[16] JoAnn Difede, Judith Cukor, Nimali Jayasinghe, Ivy Patt, Sharon Jedel, Lisa A. Spielman, Cezar Giosan, and Hunter G. Hoffman. 2007. Virtual reality exposure therapy for the treatment of posttraumatic stress disorder following September 11, 2001. *The Journal of clinical psychiatry* 68 11 (2007), 1639–47.

[17] Michael Domhardt, Martin Tiefengrabner, Radomir Dinic, Ulrike Fötschl, Gertie Oostingh, Thomas Stütz, Lars Stechemesser, Raimund Weitgasser, and Simon Ginzinger. 2015. Training of Carbohydrate Estimation for Diabetics Using Mobile Augmented Reality. *Journal of diabetes science and technology* 9 (2015), 516–524.

[18] Christian Eichhorn et al. 2021. Inspiring healthy Food Choices in a Virtual Reality Supermarket by adding a tangible Dimension in the Form of an Augmented Virtuality Smartphone. In *Conf. on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW).* IEEE, Lisbon, Portugal, 548–549.

[19] David Escárcega-Centeno, Avril Hérnandez-Briones, Erika Ochoa-Ortiz, and Yareni Gutiérrez-Gómez. 2015. Augmented-Sugar Intake: A Mobile Application to Teach Population about Sugar Sweetened Beverages. *Procedia Computer Science* 75 (2015), 275–280. 2015 Int. Conf. Virtual and Augmented Reality in Education.

[20] McGuirt et al. 2020. Extended Reality Technologies in Nutrition Education and Behavior: Comprehensive Scoping Review and Future Directions. *Nutrients* 12, 9 (2020). https://www.mdpi.com/2072-6643/12/9/2899

[21] J. R. Fernandez, M. D. Murphy, P. A. Mahajan, and C. M. Fidopiastis. 2013. The virtual supermarket: Interactive educational tools for reducing diabetes risks. In *(ICVR'13).* IEEE, Philadelphia, PA, USA, 212–213.

[22] M. Ferrer-Garcia, J. Gutiérrez-Maldonado, and G. Riva. 2013. Virtual Reality Based Treatments in Eating Disorders and Obesity: A Review. *J Contemp Psychother* 5 (2013), 207–221.

[23] Beatriz Franco-Arellano, Jacqueline Marie Brown, Quinn Daggett, Courtney Lockhart, Bill Kapralos, Ann LeSage, and JoAnne Arcand. 2024. Updating the Foodbot Factory serious game with new interactive engaging features and enhanced educational content. *Applied Physiology, Nutrition, and Metabolism* 49, 1 (2024), 52–63.

[24] Sebastian Gottschalk, Enes Yigitbas, Eugen Schmidt, and Gregor Engels. 2020. Model-Based Product Configuration in Augmented Reality Applications. In *Human-Centered Software Engineering (Lecture Notes in Computer Science, Vol. 12481).* Springer, 84–104.

[25] Sebastian Gottschalk, Enes Yigitbas, Eugen Schmidt, and Gregor Engels. 2020. ProConAR: A Tool Support for Model-Based AR Product Configuration. In *Human-Centered Software Engineering (Lecture Notes in Computer Science, Vol. 12481).* Springer, 207–215.

[26] Francisco Gutiérrez, Katrien Verbert, and Nyi Nyi Htun. 2018. PHARA: An Augmented Reality Grocery Store Assistant. In *Proceedings of the 20th Int. Conf. on Human-Computer Interaction with Mobile Devices and Services Adjunct* (Barcelona, Spain) *(MobileHCI '18).* ACM, 339–345.

[27] Barbe H, Siegel B, Müller J, and Fromberger P. 2020. What is the potential of virtual reality in clinical and forensic psychiatry? An overview of current procedures and possible applications. *Forensische Psychiatrie Psychologie Kriminologie.* 14 (2020), 270–277.

[28] Ridho Rahman Hariadi, Wijayanti Nurul Khotimah, and Eko Adhi Wiyono. 2015. Design and implementation of food nutrition information system using SURF and FatSecret API. In *2015 Int. Conf. on Advanced Mechatronics, Intelligent Manufacture, and Industrial Automation (ICAMIMIA)*. IEEE, Langkawi, Malaysia, 181–183.
[29] Dang Khanh Ngan Ho, Yu-Chieh Lee, Wan-Chun Chiu, Yi-Ta Shen, Chih-Yuan Yao, Hung-Kuo Chu, Wei-Ta Chu, Nguyen Quoc Khanh Le, Hung Trong Nguyen, Hsiu-Yueh Su, and Jung-Su Chang. 2022. COVID-19 and Virtual Nutrition: A Pilot Study of Integrating Digital Food Models for Interactive Portion Size Education. *Nutrients* 14, 16 (2022). https://www.mdpi.com/2072-6643/14/16/3313
[30] Kubra Isgin-Atici, Alper Özkan, Ufuk Celikcan, Gözde Ede, Cem Aslan, Ahmed Bülbül, Zehra Buyuktuncer, and Nuray Kanbur. 2020. Usability Study of a Novel Tool: The Virtual Cafeteria in Nutrition Education. *Journal of Nutrition Education and Behavior* 52 (11 2020), 993–1084.
[31] Haotian Jiang, James Starkman, Menghan Liu, and Ming-Chun Huang. 2018. Food Nutrition Visualization on Google Glass: Design Tradeoff and Field Evaluation. *IEEE Consumer Electronics Magazine* 7, 3 (2018), 21–31.
[32] Ivan Jovanovikj, Enes Yigitbas, Stefan Sauer, and Gregor Engels. 2020. Augmented and Virtual Reality Object Repository for Rapid Prototyping. In *Human-Centered Software Engineering (Lecture Notes in Computer Science, Vol. 12481)*. Springer, 216–224.
[33] M.-Carmen Juan, Jorge L. Charco, Inmaculada García-García, and Ramón Mollá. 2019. An Augmented Reality App to Learn to Interpret the Nutritional Information on Labels of Real Packaged Foods. *Frontiers in Computer Science* 1 (2019).
[34] Ilavarasi Kalimuthu, Mageswary Karpudewan, and Siti Baharudin. 2023. An Interdisciplinary and Immersive Real-Time Learning Experience in Adolescent Nutrition Education Through Augmented Reality Integrated With Science, Technology, Engineering, and Mathematics. *Journal of Nutrition Education and Behavior* 55 (10 2023).
[35] AbdelGhani Karkar, Tooba Salahuddin, Noor Almaadeed, Jihad Mohamad Aljaam, and Osama Halabi. 2018. A Virtual Reality Nutrition Awareness Learning System for Children. In *(IC3e'18)*. IEEE, Langkawi, Malaysia, 97–102.
[36] Lucinda Kerawalla, Rosemary Luckin, Simon Seljeflot, and Adrian Woolard. 2006. Making it real: exploring the potential of Augmented Reality for teaching primary school science. *Virtual Reality* 10 (12 2006), 163–174.
[37] Barbara A. Kitchenham, Emilia Mendes, and Guilherme H. Travassos. 2007. Cross versus Within-Company Cost Estimation Studies: A Systematic Review. *IEEE Transactions on Software Engineering* 33, 5 (2007), 316–329.
[38] Sarah Krings, Enes Yigitbas, Ivan Jovanovikj, Stefan Sauer, and Gregor Engels. 2020. Development framework for context-aware augmented reality applications. In *EICS '20*. ACM, 9:1–9:6.
[39] Sarah Claudia Krings, Enes Yigitbas, Kai Biermeier, and Gregor Engels. 2022. Design and Evaluation of AR-Assisted End-User Robot Path Planning Strategies. In *EICS '22*. ACM, 14–18.
[40] Annu Kulpy and Girish Bekaroo. 2017. Fruitify: Nutritionally augmenting fruits through markerless-based augmented reality. In *2017 IEEE 4th Int. Conf. on Soft Computing & Machine Intelligence (ISCMI)*. IEEE, Mauritius, 149–153.
[41] Cynthia Lerouge, Kathryn Dickhut, Christine Lisetti, Savitha Sangameswaran, and Toree Malasanos. 2015. Engaging adolescents in a computer-based weight management program: Avatars and virtual coaches could help. *Journal of the American Medical Informatics Association : JAMIA* 23 (07 2015), 19–28.
[42] Deborah McPhail, Gwen E. Chapman, and Brenda L. Beagan. 2011. "Too much of that stuff can't be good": Canadian teens, morality, and fast food consumption. *Social Science & Medicine* 73, 2 (2011), 301–307.
[43] Ioannis Mellos and Yasmine Probst. 2022. Evaluating augmented reality for 'real life' teaching of food portion concepts. *Journal of Human Nutrition and Dietetics* 35, 6 (2022), 1245–1254.
[44] Lam meng chun, Nur Suwadi, Adibah Huda Mohd Zainul Arifien, Bee Poh, Nik Shanita Safii, and Jyh Eiin Wong. 2021. An evaluation of a virtual atlas of portion sizes (VAPS) mobile augmented reality for portion size estimation. *Virtual Reality* 25 (09 2021), 1–13.
[45] Nazlena Mohamad Ali Muhammad Zulfakar Bayu, Haslina Arshad. 2013. Nutritional Information Visualization Using Mobile Augmented Reality Technology. *Procedia Technology* 11 (12 2013), 396–402.
[46] Takuji Narumi, Yuki Ban, Takashi Kajinami, Tomohiro Tanikawa, and Michitaka Hirose. 2012. Augmented Perception of Satiety: Controlling Food Consumption by Changing Apparent Size of Food with Augmented Reality. In *CHI'12* (Austin, Texas, USA) *(CHI '12)*. ACM, 109–118.
[47] World Health Organization. 2020. *Healthy diet - Key facts*. WHO. Retrieved December, 21, 2023 from https://www.who.int/news-room/fact-sheets/detail/healthy-diet
[48] Vávra P, Roman J, Zonča P, Ihnát P, Němec M, Kumar J, Habib N, and El-Gendi A. 2017. Recent Development of Augmented Reality in Surgery: A Review. *Journal of healthcare engineering* 2017 (2017).
[49] A Paramita, C Yulia, and E E Nikmawati. 2021. Augmented reality in nutrition education. *IOP Conference Series: Materials Science and Engineering* 1098, 2 (mar 2021), 022108.
[50] Mark Powers and Paul Emmelkamp. 2008. Virtual reality exposure therapy for anxiety disorders: A meta-analysis. *Jour. of anxiety disorders* 22 (02 2008), 561–9.
[51] Pedro Reisinho, Cátia Silva, Mário Vairinhos, Ana Patrícia Oliveira, and Nelson Zagalo. 2021. Tangible Interfaces and Augmented Reality in a Nutrition Serious Game for Kids. In *2021 IEEE 9th Int. Conf. on Serious Games and Applications for Health*. IEEE, Dubai, United Arab Emirates, 1–8.
[52] Megan E. Rollo, Tamara Bucher, Shamus P. Smith, and Clare Elizabeth Collins. 2017. ServAR: An augmented reality tool to guide the serving of food. *The Int. J. of Behavioral Nutrition and Physical Activity* 14 (2017).
[53] Inga Saboia, Cláudia Pernencar, and Mário Varinhos. 2018. Augmented Reality and nutrition field: A literature review study. *Procedia Computer Science* 138 (2018), 105–112.
[54] Pejman Sajjadi, Caitlyn G. Edwards, Jiayan Zhao, Alex Fatemi, John W. Long, Alexander Klippel, and Travis D. Masterson. 2022. Remote iVR for Nutrition Education: From Design to Evaluation. *Frontiers in Computer Science* 4 (2022).
[55] Silvia Scaglioni, Valentina De Cosmi, Valentina Ciappolino, Fabio Parazzini, Paolo Brambilla, and Carlo Agostoni. 2018. Factors Influencing Children's Eating Behaviours. *Nutrients* 10 (05 2018), 706. https://doi.org/10.3390/nu10060706
[56] Andreas Sonderegger, Delphine Ribes, Nicolas Henchoz, and Emily Groves. 2019. Food Talks: Visual and Interaction Principles for Representing Environmental and Nutritional Food Information in Augmented Reality. In *ISMAR'19*. IEEE, Beijing, China, 98–103.
[57] Thomas Stütz, Radomir Dinic, Michael Domhardt, and Simon Ginzinger. 2014. Can mobile augmented reality systems assist in portion estimation? A user study. In *ISMAR'14*. IEEE, Munich, Germany, 51–57.
[58] Debra K. Sullivan et al. 2013. Improving weight maintenance using virtual reality (second life). *Journal of Nutrition Education and Behavior* 45, 3 (May 2013), 264–268.
[59] Ruzita Talib, Wan Azdie, and Mohd Ismail. 2007. The effectivness of nutrition education programme for primary school children. *Malaysian journal of nutrition* 13 (03 2007), 45–54.
[60] Ryosuke Tanno, Takumi Ege, and Keiji Yanai. 2018. AR DeepCalorieCam V2: Food Calorie Estimation with CNN and AR-Based Actual Size Estimation *(VRST '18)*. ACM, Article 46, 2 pages.
[61] Cengiz Tuysuz. 2010. The Effect of the Virtual Laboratory on Students' Achievement and Attitude in Chemistry. *Int. Online J. of Educational Sciences* 2 (01 2010), 37–53.
[62] Georg Waltner, Michael Schwarz, Stefan Ladstätter, Anna Weber, Patrick Luley, Horst Bischof, Meinrad Lindschinger, Irene Schmid, and Lucas Paletta. 2015. MANGO - Mobile Augmented Reality with Functional Eating Guidance and Food Awareness. In *ICIAP 2015 Workshops*, Vol. 9281. Springer, Genoa, Italy, 425–432.
[63] J. Wardle, K. Parmenter, and J. Waller. 2000. Nutrition knowledge and food intake. *Appetite* 34, 3 (2000), 269–275.
[64] Wen-Chuan Wu and Yu-Han Yu. 2022. Combination of Augmented Reality with Chatbots for Visual Aids in Nutrition Education. In *2022 IEEE Int. Conf. on Consumer Electronics - Taiwan*. IEEE, Taipei, Taiwan, 203–204.
[65] Lin Yen-Ting, Wu Fang-Ni, Tsai Zi-Ying, and Huang Yu-Shan. 2023. Development of an AR Food Education System to Support Elementary School Nutrition Education. In *ICALT'23*. IEEE, Orem, UT, USA, 242–244.
[66] Enes Yigitbas, Simon Gorissen, Nils Weidmann, and Gregor Engels. 2021. Collaborative Software Modeling in Virtual Reality. In *24th Int. Conf. on Model Driven Engineering Languages and Systems*. IEEE, 261–272.
[67] Enes Yigitbas, Ivan Jovanovikj, and Gregor Engels. 2021. Simplifying Robot Programming Using Augmented Reality and End-User Development. In *INTERACT'21 (Lecture Notes in Computer Science, Vol. 12932)*. Springer, 631–651.
[68] Enes Yigitbas, Ivan Jovanovikj, Stefan Sauer, and Gregor Engels. 2019. On the Development of Context-Aware Augmented Reality Applications. In *INTERACT 2019 IFIP TC 13 Workshops (Lecture Notes in Computer Science, Vol. 11930)*. Springer, 107–120.
[69] Enes Yigitbas, Ivan Jovanovikj, Janis Scholand, and Gregor Engels. 2020. VR Training for Warehouse Management. In *VRST '20*. ACM, 78:1–78:3.
[70] Enes Yigitbas, Sebastian Krois, Timo Renzelmann, and Gregor Engels. 2022. Comparative Evaluation of AR-based, VR-based, and Traditional Basic Life Support Training. In *10th Int. Conf. on Serious Games and Applications for Health*. IEEE, 1–8.
[71] Enes Yigitbas, Stefan Sauer, and Gregor Engels. 2021. Using Augmented Reality for Enhancing Planning and Measurements in the Scaffolding Business. In *EICS '21*. ACM.
[72] Enes Yigitbas, Christopher Bernal Tejedor, and Gregor Engels. 2020. Experiencing and programming the ENIAC in VR. In *Mensch und Computer 2020*. ACM, 505–506.
[73] Enes Yigitbas, Iwo Witalinski, Sebastian Gottschalk, and Gregor Engels. 2023. Virtual Reality Collaboration Platform for Agile Software Development. In *PROFES 2023*, Vol. 14483. Springer, 3–19.
[74] Yulia, Cica, Hasbullah, H, Nikmawati, E.E., Mubaroq, S.R., Abdullah, Cep Ubad, and Widiaty, Isma. 2018. Augmented reality of traditional food for nutrition education. *MATEC Web Conf.* 197 (2018), 16001.
[75] Zhengnan Zhang, Yongquan Yang, Yaofeng Yue, John D. Fernstrom, Wenyan Jia, and Mingui Sun. 2011. Food volume estimation from a single image using virtual reality technology. In *NEBEC'11*. IEEE, Troy, NY, 1–2.