

**CocinAR: AN ADAPTABLE MULTIMODAL AUGMENTED REALITY
SYSTEM FOR DEVELOPING COOKING SKILLS IN CHILDREN WITH
COGNITIVE IMPAIRMENTS**

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Thesis submitted in partial fulfillment of the requirements for
the *Masters of Science degree in Computer Science*

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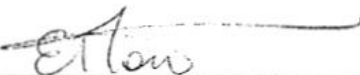
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UNIVERSITY OF CRETE
COMPUTER SCIENCE DEPARTMENT


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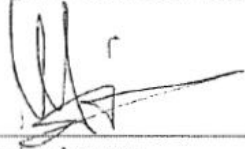
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ABSTRACT

Although activities of daily living are often difficult for individuals with cognitive impairments, their autonomy and independence can be fostered through interactive technologies. The use of traditional computer interfaces has however proved to be difficult for these users, bringing to the surface the need for novel interaction methods. This thesis proposes CocinAR, an innovative Augmented Reality system, designed to teach children with cognitive impairments how to prepare simple meals, following a playful approach. CocinAR is currently installed in the kitchen of the Rehabilitation Centre for Children with Disabilities in Heraklion, Crete, where it is used by the educators as a complementary tool in the context of their “Independent living” program.

CocinAR consists of five games, aiming to instruct children about: (i) which meals are appropriate for breakfast, lunch, supper and dinner, (ii) how to cook simple meals and (iii) fundamental rules of safety and hygiene that should be applied during the food preparation process. The system supports multimodal interaction techniques utilizing tangible objects on a table-top surface, as well as multimedia output via text, images, audio and video. Moreover, each game is designed to allow unsupervised interaction, providing context-sensitive help, easily accessible by the student. Additionally, CocinAR can be personalized to accommodate the diverse needs and dexterities of children with cognitive impairments by employing individual user profiling, while it gathers and presents statistic information for each individual user.

The development of CocinAR followed an iterative human-centered process, involving multiple assessments by User Experience experts and educators from the Rehabilitation Center in every step of the process. The system’s lifecycle started with the requirements elicitation, followed by the composition of a detailed design, which led to the first system prototype. The prototype was assessed in terms of usability in a user-based evaluation, and based on the results of this evaluation, the final system was fully implemented. The final system was installed for pilot use and was once again evaluated involving students of the Rehabilitation Center, assessing the individual design choices made, with respect to their appropriateness for children with cognitive impairments, as well as the overall user experience.

CocinAR has proved to be intuitive in its use, the interaction via tangible objects comfortable and the graphics appropriate for children with cognitive impairments. Furthermore, all children were very engaged while playing and seemed to enjoy the games. A possible improvement indicated by the evaluation concerns the recipes’ content, which could be more gradually presented, supporting cognitive limitations such as the comprehension of complex sentences.

CocinAR: ΕΝΑ ΠΡΟΣΑΡΜΟΣΙΜΟ ΠΟΛΥΤΡΟΠΙΚΟ ΣΥΣΤΗΜΑ ΕΠΑΥΞΗΜΕΝΗΣ ΠΡΑΓΜΑΤΙΚΟΤΗΤΑΣ ΓΙΑ ΤΗΝ ΑΝΑΠΤΥΞΗ ΔΕΞΙΟΤΗΤΩΝ ΜΑΓΕΙΡΙΚΗΣ ΣΕ ΠΑΙΔΙΑ ΜΕ ΝΟΗΤΙΚΕΣ ΔΥΣΚΟΛΙΕΣ

ΠΕΡΙΛΗΨΗ

Ορισμένες δραστηριότητες διαβίωσης συχνά καθίστανται δύσκολες για άτομα με νοητικές δυσκολίες, ωστόσο η αυτονομία και η ανεξαρτησία τους μπορούν να ενισχυθούν μέσω διαδραστικών τεχνολογιών. Η χρήση παραδοσιακών διεπαφών υπολογιστών όμως, έχει αποδειχθεί δύσκολη για αυτούς τους χρήστες, αναδεικνύοντας την ανάγκη για νέες μεθόδους αλληλεπίδρασης. Στην παρούσα εργασία προτείνεται το CocinAR, ένα καινοτόμο σύστημα επαυξημένης πραγματικότητας, το οποίο διδάσκει τη διαδικασία παρασκευής απλών γευμάτων σε παιδιά με νοητικές δυσκολίες, με τη μορφή παιχνιδιού. Το CocinAR είναι εγκατεστημένο στην κουζίνα του Κέντρου Αποκατάστασης για Παιδιά με Αναπηρίες στο Ηράκλειο της Κρήτης, όπου χρησιμοποιείται από τους εκπαιδευτικούς ως συμπληρωματικό εργαλείο στο πλαίσιο του προγράμματος "Αυτόνομης διαβίωσης".

Το CocinAR αποτελείται από πέντε παιχνίδια, τα οποία σκοπεύουν να διδάξουν τα παιδιά: (i) ποια γεύματα είναι κατάλληλα για πρωινό, μεσημεριανό, απογευματινό και δείπνο, (ii) πώς να μαγειρεύουν απλά γεύματα και (iii) θεμελιώδεις κανόνες ασφάλειας και υγιεινής που πρέπει να εφαρμόζονται κατά τη διάρκεια της διαδικασίας παρασκευής γευμάτων. Το σύστημα υποστηρίζει πολλαπλές τεχνικές αλληλεπίδρασης, αναγνωρίζοντας απτά αντικείμενα πάνω στην επιφάνεια ενός τραπεζιού, καθώς και πολυμεσική έξοδο μέσω κειμένου, εικόνων, ήχου και βίντεο. Επιπλέον, κάθε παιχνίδι έχει σχεδιαστεί να επιτρέπει αλληλεπίδραση χωρίς επίβλεψη, παρέχοντας βοήθεια σχετική με το εννοιολογικό πλαίσιο του κάθε παιχνιδιού, εύκολα προσβάσιμη από τον μαθητή. Επιπροσθέτως, το CocinAR μπορεί να προσαρμοστεί στις ανάγκες και τις δεξιότητες του κάθε παιδιού με νοητικές δυσκολίες, χρησιμοποιώντας ατομικά προφίλ, ενώ συγκεντρώνει και παρουσιάζει στατιστικές πληροφορίες σχετικές με την πρόοδο του κάθε μαθητή.

Για την ανάπτυξη του CocinAR ακολουθήθηκε μια επαναληπτική, ανθρωποκεντρική διαδικασία, πραγματοποιώντας πολλαπλές αξιολογήσεις από ειδικούς αξιολογητές ευχρηστίας και εκπαιδευτικούς του Κέντρου Αποκατάστασης σε κάθε της στάδιο. Η διαδικασία ανάπτυξης του συστήματος ξεκίνησε με τη συγκέντρωση των απαιτήσεων, ακολουθούμενη από τη λεπτομερή σχεδίασή του, που οδήγησε στο πρώτο πρωτότυπο του συστήματος. Η πρωτότυπη εφαρμογή εξετάστηκε ως προς την ευχρηστία σε μια αξιολόγηση με χρήστες, στα αποτελέσματα της οποίας βασίστηκε η ανάπτυξη του πλήρους συστήματος. Το τελικό σύστημα εγκαταστάθηκε για πιλοτική χρήση και εξετάστηκε και πάλι με τη συμμετοχή μαθητών του Κέντρου Αποκατάστασης, με σκοπό την αξιολόγηση των διάφορων σχεδιαστικών επιλογών, ως προς την καταλληλότητά τους για παιδιά με νοητικές δυσκολίες, καθώς και τη συνολική ευχρηστία του συστήματος.

Το CocinAR αποδείχθηκε διαισθητικό στη χρήση, η αλληλεπίδραση μέσω απτών αντικειμένων άνετη και τα γραφικά κατάλληλα για τα παιδιά με νοητικές δυσκολίες. Επιπλέον, όλα τα παιδιά ήταν πολύ απορροφημένα ενώ έπαιζαν και φαινόταν να διασκεδάζουν με τα παιχνίδια. Μια πιθανή βελτίωση που υποδείχθηκε από την αξιολόγηση αφορά το περιεχόμενο των συνταγών, το οποίο θα μπορούσε να παρουσιαστεί πιο σταδιακά, υποστηρίζοντας νοητικούς περιορισμούς όπως η κατανόηση σύνθετων προτάσεων.

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στους γονείς μου
Παναγιώτη & Μαρίνα...

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1 INTRODUCTION

Cognitive impairment is an inclusive term used to describe deficits in intellectual functioning, and entails limitations in specific operations, such as conceptualizing, planning, and sequencing thoughts and actions, remembering, interpreting social cues, and understanding numbers and symbols [13]. Although the specific functional limitations may vary from profound mental retardation with minimal functioning to mild impairment with difficulties in specific operations, a common problem among people with cognitive impairments is self-management and carrying out everyday tasks, such as bathing, eating, preparing simple meals, etc. To this end, cognitive technologies have the potential to help individuals with cognitive disabilities to become more independent and enhance their quality of life [13].

However, accessing a computer and using a typical GUI can be a challenging task for users with a cognitive disability. For example, simple interface actions such as double-clicking, using scroll bars, or reading menu items and button labels can present barriers to use for these individuals [117]. On the other hand, alternative interaction means and multimodal input may benefit cognitive impaired users, while multisensory output may alleviate difficulties in comprehending written text [95].

Meal preparation is an important skill to teach to individuals with cognitive disabilities in order to increase their independence. To this end, several technological approaches have emerged, aiming either to facilitate adults during the cooking process or to cultivate cooking skills in youngsters. This work introduces a series of educational games developed to familiarize children with cognitive impairments with elementary meal preparation notions in a playful way. Progress beyond the current approaches lies in the adoption of a novel interaction style, combined with the adaptability of the system to the needs of each individual child, through profiling mechanisms.

CocinAR is an Augmented Reality (AR) system that has been developed to help teaching children with cognitive disabilities how to prepare simple meals. It is installed in the kitchen of the Rehabilitation Centre for Children with Disabilities in Heraklion, Crete (from now on Rehabilitation Centre or RC), where it is used by the educators as a complementary tool in the context of their “Independent living” program, in which children are trained to execute simple recipes. Aiming to facilitate the uninterrupted and comfortable interaction of children with cognitive impairments, CocinAR supports multimodal interaction utilizing tangible objects on a table-top surface and multimedia output available in textual, auditory and pictorial form. Profiling functionality is supported, allowing system’s personalization and adaptability with respect to the preferred output modalities and providing to the teachers statistic information on the progress of each student through time.

An iterative process was followed throughout the entire development lifecycle of CocinAR, shown in Figure 1 involving multiple assessments by User Experience (UX) experts and educators from the Rehabilitation Center (RC), who are using the system together with the children. The system was also tested in two user-based evaluations involving children with cognitive impairments. The iterative process

aimed to ensure the best possible fulfillment of the educators' requirements in terms of functionality, content and overall UX, as well as the real needs of the children.

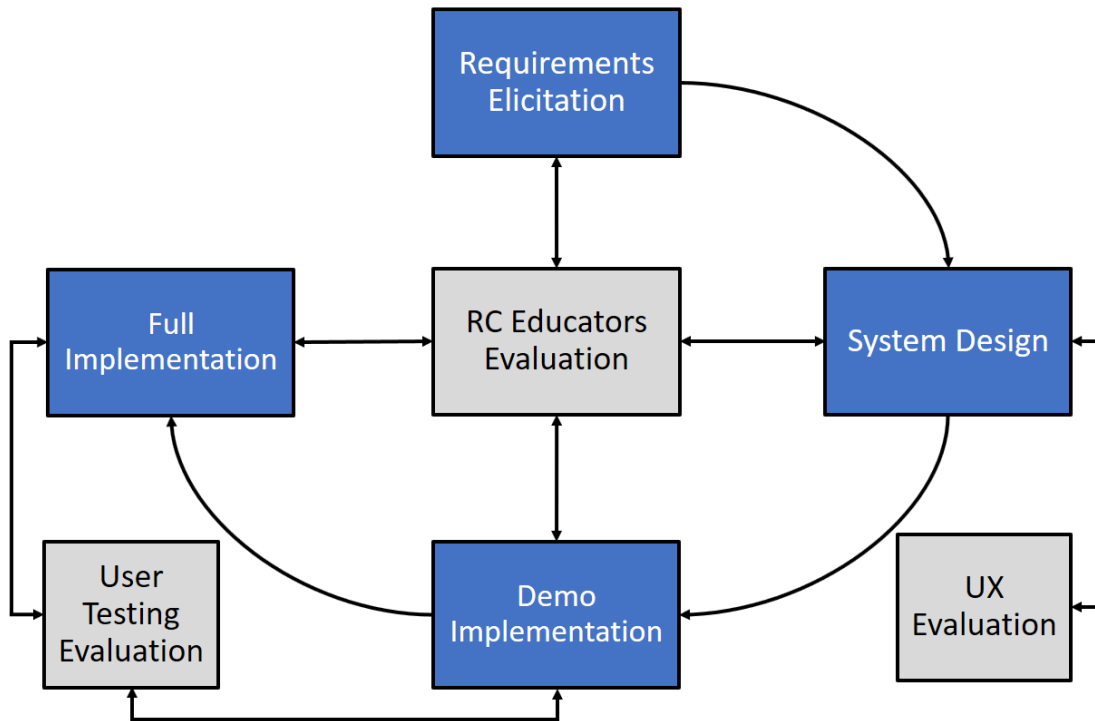


Figure 1. The development lifecycle of the CocinAR system.

In more details, the target users' characteristics, as well as the main functionalities of the system, were specified in cooperation with the teachers of the RC and analyzed to produce the final requirements specification, which was evaluated by the same RC teachers. As a subsequent step, detailed design prototypes were produced depicting the full functionality of the system, which were again evaluated by the RC's educators. Based on the specification, a prototype was implemented featuring a representative part of the foreseen functionality. The prototype's implementation was followed by an evaluation experiment involving children of the RC, with the aim to assess the produced designs as well as the various interaction modalities and system setups. Finally, based on the results of the evaluation, a full version of the system was implemented and installed at the Centre for pilot use and further evaluation. The second evaluation was conducted in order to examine whether particular design tactics used were appropriate for children with intellectual disabilities, as well as the impact of the multimodality in the overall user experience.

The structure of this thesis is as follows. First, the current state of the art regarding designing for users with cognitive impairments is presented in the Chapter 2, where the different approaches that exist in literature and are related to the characteristics of CocinAR are presented, analyzed and discussed. Chapter 3 proceeds with the description of the requirements specification and the detailed functional and non-functional requirements that occurred, while Chapter 4 explains the design choices made, based on these requirements. The system's implementation and architecture is analyzed in the Chapter 5, while the user-based evaluations and their results are discussed in Chapter 6. Finally, this work concludes suggesting possible, future refinements and developments of the system in Chapter 7.

2 STATE OF THE ART

Cognitive impairment is an inclusive term used to describe deficits in intellectual functioning, and entails limitations in specific operations, such as conceptualizing, planning, and sequencing thoughts and actions, remembering, interpreting social cues, and understanding numbers and symbols [12]. According to [31] intellectual disabilities, also known as developmental delay or mental retardation, are a group of disorders defined by diminished cognitive and adaptive development. Affecting more males than females, they are diagnosed in between one and three percent of the population. Cognitive impairment is a broad concept encompassing various intellectual or cognitive deficits, including intellectual disability, deficits too mild to properly qualify as intellectual disability, various specific conditions (such as specific learning disability), and problems acquired later in life through acquired brain injuries or neurodegenerative diseases such as dementia. A cognitive disability can be determined by the person's intellectual functioning and adaptive behavior [31].

Intellectual functioning refers to a person's ability to plan, comprehend, and reason. More specifically, there are three kinds of cognitive disability based on intellectual functioning:

- a) Mild cognitive disability: Accounting for around 85% of all cognitive disabilities. Kids in this category have IQ scores between 55 and 70 and are usually included in the regular classroom.
- b) Moderate cognitive disability: Students with this type of disability have IQ scores between 30 and 55.
- c) Severe cognitive disability: Kids with severe cognitive disabilities have IQ scores that fall under 30 and will have few communication skills, and will need direct supervision. Of all cognitive disabilities, only about 3 to 4% of children have a severe cognitive disability.

Adaptive behavior refers to an individual's ability to apply social and practical skills in everyday life. Examples of adaptive behavior can include personal care, social problem-solving skills, dressing and eating skills, using money, and following rules [31].

Although specific functional limitations may vary from profound mental retardation with minimal functioning to mild impairment with difficulties in specific operations, a common problem among people with cognitive impairments is self-management and carrying out everyday tasks [95]. To this end, cognitive technologies have the potential to help individuals with cognitive disabilities to become more independent and enhance their quality of life [12].

Technology has been claimed to improve performance and independence of individuals with disabilities in comparison to more traditional means, such as pictorial prompts, tactile prompts or auditory prompts [81,72]. Common assistive technologies include software for reminding and prompting, task guidance, remote assistance from caregivers, computer assisted learning and communication [12,116,71]. This section reviews technological approaches relevant to the current thesis and their application for children with cognitive impairments. In more details, the following technologies are reviewed: augmented and

mixed reality, computer games and cognition, user interaction techniques, multimodal and adaptable systems, information provision, as well as technologies supporting meal preparation in the context of independent living. This section concludes by discussing the contributions of the current work, and how it advances beyond the state of the art.

2.1 AUGMENTED AND MIXED REALITY

Augmented Reality (AR) allows virtual imagery to augment and enhance physical objects in real time. Users may interact with the virtual images using real objects in a seamless way [135]. Augmented objects can be used for providing implicit or explicit input to systems while their physical and mental existence as computational devices disappears [125]. Three characteristics that are integral to an augmented reality interface have been defined [7]: it combines the real and the virtual, it is interactive in real time, and it is registered in three dimensions.

Mixed reality (MR), encompassing both augmented reality and augmented virtuality, refers to the merging of the real and the virtual world in order to produce a new environment and visualization, where physical and digital objects co-exist and interact in real time. In other words, mixed reality is a mix of reality, augmented reality, augmented virtuality and virtual reality [84]. More specifically, MR refers to the incorporation of virtual computer graphics objects into a real three dimensional scene, or alternatively the inclusion of real world elements into a virtual environment. The former case is generally referred to as augmented reality, and the latter as augmented virtuality.

Single user Mixed Reality interfaces have been developed for computer aided instruction [36], manufacturing [27] and medical visualization [8]. These applications have shown that MR interfaces can enable a person to interact with the real world in a way that was never before possible. As an instance, virtual ultrasound images can be overlaid onto a patient's body, allowing doctors to have "X-Ray" vision while performing a needle biopsy task [8]. On the other hand, the design of MR systems gives rise to new challenges due to the novel roles that physical objects can play in interactive systems. In addition to the design of mixed objects, interacting within such mixed environments composed of physical, mixed and digital objects, involves novel interaction modalities and forms of modalities that require new interaction models [26].

In particular, Mixed Reality systems have been can be implemented in various contexts, such as computer-aided design [34], arts, games, learning and entertainment [18] [93]. With respect to learning, Mixed Reality has the potential to:

- **Enable constructivism and experiential learning:** virtual environments are unique in their usefulness to education due to their characteristics of autonomy, presence and interaction [133]. These are in

line with important paradigms in learning, such as experiential education and constructivism [15]. Experiential education theory has been widely accepted as a useful framework for learning-centered educational innovation [64], while the combination of constructivist learning theory and the use of technology seem to produce optimal applications of technology tools to facilitate learning [39].

- **Enable social or collaborative learning:** The recent years have witnessed substantial developments in theorizing and experimentation in the field of social learning. Social learning theory is particularly suited to deal with group performance as well as individual responding [112]. Multi-user virtual environments and augmented reality could help meet the need for social learning [30]. Collaboration is considered useful to the learning process because students have to articulate and debate their positions, thereby leading to reflection and co-constructed knowledge [52].
- **Foster presence:** allowing students to feel a sense of presence in the virtual world enables VR learning systems to increase motivation [85]. Research in the domain of educational virtual environments [83] has provided feedback that factors such as environmental richness and a high level of interactivity contribute to a high degree of presence, which was in turn associated with knowledge construction.
- **Enhance interactivity:** interactivity is generally seen as an intrinsic feature of educational practice in the sense of social communication, but also as an inherent property of any interactive multimedia or virtual reality environment that promises physical and sensor - in addition to mental - activity and response [125]. According to [126], interactivity is examined in two ways - the first is a generic view relating to the frequency of interaction, the range of choices when interacting with the system and the significance of those choices; the second, specific to virtual environments, is defined as the tight coupling of head-tracked (and other) user input with multisensory display, so users perceive themselves as present in the environment. As to the importance of interactivity, it is argued [113] that there is a strong relationship between interactivity, engagement and learning.

Augmented reality is designed to augment the real world; therefore, the effective use of sensors in physical environments is vital. Physical components allow a software system to sense and act upon the environment while software algorithms rely on sensory data from the real world in order to perceive the user input and determine the action that should be taken to change the state of the system. The recent growth of depth cameras enabled better tracking of hand posture and facilitated tangible interaction upon arbitrary surfaces [46]. Computer vision is a passive method that requires minimal intervention to observe the environment and, thus, facilitates seamless interaction in classroom or home study.

An example based on Computer Vision techniques is the **reactIVision**¹, a standalone application. ReactIVision is an open source, cross-platform computer vision framework for the fast and robust tracking of fiducial markers attached to physical objects, as well as for multi-touch finger tracking. It was mainly designed as a toolkit for the development of the **Reactable**², a table-based tangible user interface and multi-touch interactive surface. Similar recognition techniques have also been adopted in the Farm Game

¹ <http://reactivision.sourceforge.net/>

² <http://www.reactable.com/products/>

[77], which uses fiducial techniques in order for small robots to be recognized in an augmented game environment [63], and also by **ARToolKit** used to develop a board game with a tangible interface [10].

Computer Vision has the potential to recognize a variety of input, from plain, printed matter to human body parts. Some AR applications that focus on printed matter recognition are the Augmented School Desk [5] where computer Vision is applied for page recognition, The Gamebook [14] for cards recognition and The book of Ellie [99] for book, cards and touch recognition. Object recognition is yet another use of Computer Vision whose example applications include iEat [78] implemented for dish and pen recognition and Micromotorcross [131], which is a driving simulation game that allows players to drive a virtual car over real objects placed on a table. Macrographia [42] and Aml Playfield [100] are applications that use Computer Vision for body tracking in AMI environments. Last but not least, stylus recognition has been successfully used in applications like SESIL [79] and C-Slate [51] which utilizes stylus input to support remote collaboration.

2.2 COMPUTER GAMES AND COGNITION

Play, in all its contemporary and digital forms, be it through games, social networks, applications on smartphones, interactive toys, or through interactive art, is an important activity of life [114]. Serious games incorporate elements of serious applications and aim to teach, exercise, and change users' behavior [41]. Technologies like Augmented Reality (AR) have the ability to catch the children's imagination and to maintain the children's attention, combining fun elements with serious purposes, which is the common property of both playful interactions and serious games.

Over the past few years, teaching methods have adopted serious games as a means of increasing the efficiency of learning methods [132]. With AR it is possible to create more attractive and interactive interfaces that can be manipulated by hand, without using conventional peripherals such as the keyboard or the mouse [110]. This characteristic of AR promotes the interaction between the child and the object, raising their interest and curiosity in the activity. As stated in [6], AR has grown exponentially because it allows improving the users' understanding, knowledge and interaction with the real world.

Playing and cognition are deeply interconnected and with the advent of computer games new scientific interests for their relation emerged. To better understand the connection between computer games and cognition, Lindley and Sennersten [70] proposed a model based on the assumption that learning "how to play" a computer game implies the following cognitive skills:

- **Interaction mechanisms** - Player needs to learn how to manage interaction mechanisms, such as using the mouse or the remote appropriately.

- **Interaction semantics** - Player needs to get familiar with interaction semantics, which means associations between physical actions (such as pressing a key) and the corresponding movement in the in-game environment.
- **Game Expertise** - Player should acquire game expertise, which would allow them to perform the right action at the right moment. While the first two skills become unconscious and automatic in a very short period, game expertise evolves according to the new challenges proposed by the game played.
- **Decision-making** - Decision-making can be considered as one of the main cognitive processes underlying game playing expertise, and it cannot be set apart from the attention paid to the context-related contingencies as well as from previous experience.
- **Motivation** - Scientific investigation in areas such as learning or training has also considered another important variable playing a role in the relation between games and cognition, namely motivation. Playing can be a good “motivator” for the student who has to learn a lesson.

Many researchers agree that digital learning games have everything it takes to become an effective learning medium [24, 90, 107, 111], being both entertaining and educational. The entertainment dimension highlights the emotional experience, which increases the attractiveness of the game beyond its educational aim, and involves every age; for these reasons games can be considered powerful tools for training in clinical settings [47, 89].

The use of digital games can stimulate cognitive skills and contribute to the development of persons with disabilities [28]. In particular, it can contribute to motor development, communication, and other cognitive processes of persons with disabilities [28]. According to [60], access to computer games through configurable and usable input devices would, by their own admission, enhance the lives of children with disabilities. In other words, digital learning games can be regarded as an entertainment medium designed to bring about cognitive changes in its players. More specifically, the findings of [66] suggest that serious gaming interventions may be effective for reducing disorder-related symptoms.

Using AR in games offers opportunities for more natural and improved interaction, because play is no longer confined to a television or computer screen, but can extend to the real world, using everyday objects as interaction devices [105, 130].

2.3 TABLE-TOP USER INTERFACES

AR systems often involve interaction of the user on an augmented table surface. The first approaches toward augmented interactive surfaces [103, 62] concerned the projection of visual content on convenient surfaces in the environment, such as the walls or the floor of a room. Having selected the

surfaces a priori, a projector was steered to display upon the surface of choice. Images were pre-warped according to the orientation of the surface, so as to appear undistorted after projection. Using a more detailed 3D model of the whole scene, projections can appear undistorted at virtually any geometry of surfaces [57]. This way of pervasively augmenting information is still useful, along with conventional displays, as a means of creating pervasive and ergonomic displays for study [80].

In recent years, classrooms have been digitally augmented by replacing conventional blackboards and tables with computer-augmented surfaces provided with image projection and multi-touch interaction [77]. Henceforth, the educational community is taking a special interest in creating pedagogical content for multi-touch-based tables (or tabletops). Many tabletop-based projects have focused on the new possibilities that multi-touch active surfaces offer for co-located learning [119,92]. There are several recent examples of tabletop applications for children within research prototypes. Examples are Futura [4], a collaborative, multi-touch, learning game in which the players try to support a growing population on a table, and PAR [120], a multiuser collaborative game for people with autism, which supports multi-touch tabletop interaction. Another interactive surface concept for Mixed Reality (MR) tabletop games combines a variable (LCD and/or projection) screen configuration with the detection of finger touches, in-air gestures, and tangibles [37].

However, problems emerge when tabletop devices based on multi-touch interaction are used by very young children or children with physical and cognitive disabilities on the grounds that their fine motor skills may not be sufficiently developed [76, 45] and this kind of interaction requires fine muscle coordination [20]. Pointing devices can be used to address this issue, which can be particularly convenient, especially in cases of users with difficulty in hand gestures [80]. Other alternatives have appeared based on hybrid physical board games and computer-augmented surfaces, keeping playing pieces in the players' physical environment [75,48], introducing a new interaction style, the "Tangible User Interfaces".

2.4 TANGIBLE USER INTERFACES

Tangible User Interface (TUI) has been proposed and studied [56,101,129] as a novel interaction style which employs a physical artifact as part of its UI components. Such artifacts can be a physical representation of a digital object or act as a control for the manipulation of a digital object/information [50]. The use of tangible material stimulates multiple senses and promotes the development of cognitive functions and perceptual and bodily skills [38]. One of the TUI benefits commonly cited is its ease of use [96]. Others include a richer multimodal interface, increased task engagement, and exploratory learning [68].

There are strong cognitive-developmental reasons why interacting with task-appropriate physical objects is a very promising learning approach for young children. Embedding interactivity into physical objects allows supporting traditional exploratory play with physical objects that can be extended and enhanced by the interactive power of digital technology [109]. Direct manipulation of physical objects also reduces cognitive effort while interacting with a computer system. By utilizing such naturally developed skills, TUI advantages include better efficacy for some computer-assisted tasks and ease of computer usage. It has been reported that a computer system with TUI is more accessible to young children, people with learning disabilities, and novice computer users [68,138].

On the other hand, children build their mental image of the world through action and motor responses and, with physical handling, they become conscious of reality [19]. Therefore, it is desirable that computer activities in schools combine the pedagogical benefits of digitally augmenting educative activities [115] and co-located learning with small groups of children actively playing with physical materials.

Educational games based on physical cards (no electronic media or computer involved) have been studied in the context of assessing the educational effects of the approach [123]. Such examples include the “Voyager: Satellites” card game [29] and the “Trading Card Games” [98], whose prominent characteristic is that of using illustrated cards to captivate the learner interest and reinforce his/her motivation. Purely electronic card games (played on the computer screen) have also been studied in the same context, such as “Binary Numbers” [73], where students learn the binary system by playing a variation of the “Blackjack” card game against the computer. In the domain of Augmented Reality, the “Educational tabletop mini games” [74] are played with physical cards, which are visually recognized, and have been developed in the context of an Ambient Intelligence classroom [8], [67]. Additionally, cards have been used on computer-augmented tabletop surfaces to reinforce the learning of reading skills [122] and math [61] for 5-to-7-year-old children.

There are several recent examples of tabletop applications for children that incorporate TUIs, such as SaP [2], a multi-player table-top game which employs tangible tiles to activate projected on-table buttons, and Read-It [122], another interesting application for young children which uses tangible brick elements as means of interaction and teaches them to read in a tabletop environment. A very interesting table-top approach is “Beantable” [136], which supports preschool children’s development through playing and can be interacted with via touch, augmented objects and physical cards.

An experiment with children with low-functioning autism examined the ease-of-use and learning efficacy of TUIs by studying three systems that differed in terms of interaction: a mouse-based system, a touch-based system and a tabletop TUI interface [121]. Although the results showed slightly better results in terms of the system’s ease of use for the touch-based system, the subjects did not show the same affection or enthusiasm to use the system as for the TUI-based system case. In terms of learning efficacy, the TUI-based system produced the best result among the three training methods, which was attributed to the strong lesson engagement of the subjects in this group.

Studies have provided promising results about the accessibility and benefits of tabletop applications with TUI, making computers accessible to children with cerebral palsy [69] and to children with social disorders [104,9]. However, studies that combine tabletop devices and TUIs applied to children with cognitive disabilities remain scarce and of a preliminary nature [106].

2.5 MULTIMODAL AND ADAPTABLE SYSTEMS

Multimodal interaction is part of everyday human discourse: we speak, move, gesture and shift our gaze in an effective flow of communication. Jaimes et al. [53] define a multimodal system as a system that “responds to inputs in more than one modality or communication channel, such as speech, gesture, writing and others”. Multimodal user interfaces support interaction techniques which may be used sequentially or concurrently, and independently or combined synergistically [33].

Multimodal interfaces are generally intended to deliver natural and efficient interaction, but it turns out that there are several specific advantages of multimodality [128]. Various studies have shown that multimodal interfaces may be preferred by users over unimodal alternatives, can offer better flexibility and reliability, and can offer interaction alternatives to better meet the needs of diverse users with diverse usage patterns and preferences [44, 45]. Other potential advantages of multimodal interfaces according to [97, 128] include the following:

- They permit the flexible use of input modes, including alternation and integrated use.
- They support improved efficiency, especially when manipulating graphical information.
- They can support greater precision of spatial information than a speech-only interface (e.g., pen input can be quite precise).
- They give users alternatives in their interaction techniques.
- They lead to enhanced error avoidance and ease of error resolution.
- They accommodate a wider range of users, tasks, and environmental situations.
- They are adaptable during continuously changing environmental conditions.
- They accommodate individual differences, such as permanent or temporary functional limitations.
- They can help prevent overuse of any individual mode during extended computer usage.

An important attribute of multimodal systems is adaptability, which supports adaptation to the needs and abilities of different users, as well as different contexts of use. Adaptability refers to self-adaptation which is based on knowledge (concerning the user, the environment, the context of use, etc.) available to (or, acquired by) the system prior to the initiation of interaction, and which leads to adaptations that also precede the commencement of interaction [124]. Individual differences (for example, age, preferences,

skill, sensory or motor impairment) can be captured in a user profile and used to determine interface settings [108].

2.6 COMPUTER-ASSISTED INSTRUCTION

According to [59], a powerful learning environment is one that not only elicits deep learning, but also enhances the learners' motivation to learn. Many studies have shown that it is possible to promote deep learning by encouraging learners to carry out specific activities during the learning task [127]. These activities can be triggered by the presence of features such as feedback [91]. Feedback in educational games appears to reduce redundant cognitive processes, by supplying learners with schemas to help them correct their comprehension errors [23].

Digital learning games differ from classic learning modules in the nature of the instructions given to learners. These instructions may direct students toward educational goals, but they may also encourage them to pursue more playful ones [24]. However, it is a fact that some children with language, literacy, and communication disorders may find written information tedious to master [35].

Computer-Assisted Instruction (CAI) refers to the use of a computer technology to present learning materials and/or check a learner's knowledge [3]. In a research reported in [87] on social rules and children with Autism Spectrum Disorders (ASD), it was claimed that computer programs can be designed to highlight, slow down, and repeat critical social cues, thus teaching social contingencies in controlled formats. Researchers have suggested that individuals with ASD may find the multisensory interactions of CAI to be reinforcing. D. Moore et al. [88] suggested that such individuals might benefit from the incorporation of preferred stimuli into multimedia programming. Also, these students not only have been shown to exhibit fewer inappropriate behaviors during CAI than during traditional one-on-one instruction [22,88] but have also expressed enjoyment and exhibited increased appropriate behaviors during CAI [11,49].

CAI also may be effective for addressing impairments in communication during instruction. J. Janzen [55] suggested that differences in cognitive processing might often render spoken language transient for many individuals with ASD. The controlled multimedia presentation of stimuli during CAI affords the learner a visual prosthesis during instruction. These visual prostheses may benefit students during instruction by increasing the salience of instructional stimuli [102].

Individuals with cognitive impairments may also benefit from the use of computer-generated speech during CAI. According to [118] the characteristics of computer-generated speech (e.g., monotone, limited-affect) might be preferable to them because of their decreased ability to detect changes in prosody and their preference for emotionally 'neutral' stimuli. In addition, the recorded audio features of computer-

based technologies might provide learners with the opportunity to replay missed directions and auditory cues.

2.7 MEAL PREPARATION

Activities of daily living (ADL) are routine self-maintenance tasks. These functional activities correspond to eating, dressing, hygiene, and communication habits [44]. According to the level of cognitive impairment, children may have difficulties in the performance of ADL and lower social participation in household tasks [16]. Promoting ADL performance has been the focus of interventions by many professionals and researchers and these interventions may be directed toward different objectives, so that the child acquires the greatest possible level of independence and autonomy in actions such as eating, taking a bath, performing personal hygiene, and dressing [28]. In the promotion of ADL, although parental practices significantly influence functional development and the level of independence of children with cognitive impairments, the important contribution of different interventions and therapeutic processes is recognized [28].

Meal preparation is a skill that has been considered important to teach to individuals with cognitive disabilities in order to increase their independence. To this end, several traditional and technological approaches have emerged, while comparative studies have also been carried out. Lancioni et al. [65] introduce a palm-top computer involving pictorial instructions as well as auditory and vibratory mechanisms for preparing four different meals, compare it with a card system and conclude that participants had higher performance with the computer system and preferred it. Mechling et al. [82] studied the use of a self-prompting PDA system using video, picture and auditory prompts to instruct individuals with autism to prepare three cooking recipes and found that it can be an effective assistive medium for performing multi-step tasks. Beyond traditional technologies, Giroux et al. [40] describe a smart home environment aiming to assist individuals with cognitive impairments in cooking tasks, by presenting the recipe steps through pictures or video and assisting them in locating objects or ingredients in the kitchen. Another step-by-step approach for guiding individuals with cognitive impairments through a food preparation recipe is the ARCoach system [21]. ARCoach uses computer vision to recognize the various ingredients on a table and the user's actions, so appropriate feedback is provided when there is an abnormality in a step execution. Last but not least, another system which supports the meal preparation process is described in [86]. This system is aimed at supporting people with higher brain dysfunction and focuses on assisting their memory and planning-ability through multimedia recipe presentation. Each recipe step is presented on a screen and can be interacted with by a remote controller.

Learning how to cook is a complex process that includes the understanding of cultural artefacts such as recipes. Just as notes can be understood as mediating artefacts in learning music, recipes are mediating

artefacts when learning cooking [17]. One example of a system that aims to assist the better comprehension and use of cooking recipes is the CounterActive [58], an interactive cookbook. This system provides an augmented version of a cookbook, projected on the user's kitchen counter and can be interacted with via touch. Another interesting application that provides a first cooking experience with recipes to young children is described in [54]. This work is about an AR cooking system which uses a tabletop screen to display the system's interface, while an interactive miniature kitchen is set next to the display. The interaction is accomplished via markers which correspond to cooking elements on the miniature kitchen and specific touch gestures on the tabletop display which indicate the various commands (e.g., break egg, turn on fire etc.).

2.8 PROGRESS BEYOND THE STATE OF THE ART

The CocinAR system presented in this thesis is an AR educational game that was developed to enhance the independence of children with cognitive impairments by cultivating basic cooking skills. Several approaches exist for assisting individuals with cognitive impairments during the meal preparation process, however, CocinAR's development was driven by the vision of children growing into independent-cooking adults, without the need of any supportive systems. To that end, a collaborative design process was followed, involving multiple sessions with experts in the field of cognitive disabilities, who will be using the system for their everyday cooking sessions with children with cognitive impairments.

The proposed system is a table-top Augmented Reality system, which features tangible interaction through cards, adopts a playful approach and through multimodality aims to ensure that the system is usable by children with cognitive impairments with diverse needs and dexterities. Furthermore, CocinAR delivers instructions in a step-by-step manner, supports multimedia output to cater for the diverse needs of the target audience, and employs multimedia as a reward mechanism.

Although the technological aspects used have been incorporated in various systems, their combination constitutes a novel approach in developing cooking skills to children with cognitive impairments. More specifically, the novel contribution of this system concerns the combination of the following aspects into one educational system:

- **Table-top Interaction** – CocinAR was carefully designed in close collaboration with a Rehabilitation Center's experts in order to achieve an intuitive and comfortable learning environment for the children. The combination of table-top interfaces with interaction via physical objects when used with children with cognitive impairments has elicited promising results in the past, so CocinAR adopts this interaction style aiming for the optimal user experience.

- **Multimodality and multimedia output** - CocinAR supports multimodal input and multimedia output. Regarding the input, the system supports interaction via both physical cards, a stylus, and a custom made pointing device. The system's output can be presented in multiple, combined if required, forms, depending on the user's preferences, such as text, images, audio, and symbols.
- **Teacher vs student design** – A double design strategy was followed throughout the design process in order to support not only the students but also the teachers using the system. As a teacher-assisting tool, CocinAR provides context-related information about the student in every part of the session, system management tools and customization settings. All this functionality, if not used, remains hidden from the student avoiding unnecessary cognitive load.
- **The stamp** – Since tabletop touching approaches require fine muscle coordination, an innovative 3D-printed pointing device, similar to a stamp, was specially designed to support children with motor difficulties. The innovative feature of the stamp is its physical design, as it is designed to support four different handles to accommodate different grip sizes and possible motor impairments.
- **Personalization** - Another significant aspect of the CocinAR system is the profile and history functionality. The profiling offers customizable settings for each user, making it ideal for use by children with a wide range of cognitive skills, while due to the game history kept, the teacher can track every child's progress through time and define possible cognitive weaknesses. In addition, the statistical data kept will be, over time, a valuable source of information not only for the teachers using the system, but also for research purposes.

Finally yet importantly, all the aforementioned design choices were evaluated in terms of usability, ease-of-use and affection by 12 children and their teachers at the Rehabilitation Center. The results of the evaluation are presented in a structured way and the derived conclusions from the results' analysis are discussed.

3 REQUIREMENTS ANALYSIS

This chapter illustrates the requirements for the development of CocinAR, as they were defined prior to system's design. Firstly, the process that was followed is described in details, stating the different approaches that were adopted in order to achieve optimal results. Secondly, the characteristics of the target user groups are presented and their requirements are analyzed. Finally, the system's functional requirements are reported.

3.1 REQUIREMENTS ELICITATION

Requirements elicitation was initially carried out through questionnaires, which are generally used to ensure that fundamental elements are addressed early on, and to establish the foundation for subsequent elicitation activities [137]. Subsequently, semi-structured interviews [32] were conducted with the educators of the Rehabilitation Center (RC), aiming to define the targeted user groups' characteristics and develop the exact specifications of the system's characteristics. The requirements acquired were analyzed and the detailed functionality of the system was evaluated in a focus group setting by twelve educators of the RC, promoting active encouragement and exchange of ideas [25]. Based on the final system requirements, detailed mockups were designed following an iterative process. The participation of educators was of uttermost importance in order to follow a User-Centered Design approach, given the difficulties entailed in involving children with cognitive disabilities themselves in the design process.

3.2 USER GROUPS

CocinAR is an educational system implemented for children with cognitive impairments, but at the same time it is a teacher-assisting tool, directed to the RC's educators. Therefore, the system addresses two different user groups: the RC's teachers and the children with cognitive impairments visiting the Centre for rehabilitation.

The professional expertise of the RC's educators expands in various domains, including among others a speech therapist, psychologists, occupational therapists, nursery staff, a pediatrician and a health visitor. A characteristic of this user group is that in general they have little experience with computers. They usually follow traditional teaching approaches using cards, pictures, and toys, while few of them actually use a computer in their everyday life. Nevertheless, all of them were positive towards incorporating new technologies in the activities of the RC, realizing the potential benefits and recognizing that children are

eager to engage with technology. Although IT had only been used as a teaching medium through PowerPoint presentations, it was evident that children attended these activities focused, with high interest, and active participation.

The characteristics and requirements of the second user group, children with cognitive impairments, were elicited with the help of the RC educators, who have great experience when it comes to the needs and preferences of these children. Regarding the students of the RC, a generic characteristics' classification was not feasible, since each child has different skills, traits and functional limitations. In more details, the second target group of the system was defined as follows:

- Children's physical age ranges from preschoolers (3-4 years old) to teenagers, with the corresponding variations in physique. Physical variations such as height can limit or facilitate particular actions like pointing and reaching.
- Cognitive age is a non-chronological age variable, which is related to intelligence and is used to express the level of a person's intellectual maturity. In the specific case, the cognitive age varies independently of the child's physical age. According to the RC's educators, the range of cognitive ages starts from preschoolers (3-4 years old).
- Reading skills may vary from minimum to excellent. Some children are able to read regular text fluently, while children with deteriorated skills may recognize short phrases, individual words and texts read aloud, requiring thus the use of simplified language. A small proportion of our user group is unable to read, in which case images and symbols are used instead of written text in their daily courses.
- None of our users suffers from hearing impairment, therefore they can successfully understand text when it is read aloud. However, a slower reading rate may be more appropriate for some children.
- Additionally, another variable characteristic among the user group is their gross and fine motor skills. The gross motor skills include the larger movement of arms and legs while the fine motor skills refer to smaller actions, such as grasping an object between the thumb and a finger. In our case, some children suffer from inability to move their upper limbs, while others may have difficulty separating their fingers. There is also a portion of users with satisfactory gross motor skills and upper limb sufficient mobility.
- No important visual impairment has been observed among the targeted user group, apart from minor anomalies. The most common visual problems noticed include color blindness and difficulties in reading small size fonts.
- Another common characteristic of children with cognitive impairments refers to eye-hand coordination problems. These children have difficulties utilizing specific pointing technology (e.g., the computer mouse), which requires this particular skill.

- It is common among children with cognitive impairments to exhibit a variety of individual traits, such as placing objects in mouth, spitting, and carrying out involuntary movements. This may result in the destruction of hand-held objects unless resilient materials are used.

3.3 FUNCTIONAL REQUIREMENTS

The system functionality and specifications were determined according to the characteristics presented in the previous section, and taking into account the educational goals that the RC educators need to achieve when training children towards meal preparation. This section describes the general functional requirements of the system, as well as the specific functions of each game.

3.3.1 SYSTEM CHARACTERISTICS AND OVERALL FUNCTIONALITY

The system should be able to accommodate a large variety of skills. In summary, the system should (i) support multimodal information presentation, (ii) accommodate individual user profiles, (iii) allow customizations according to the needs of each user (iv) provide context-sensitive help in each individual exercise, and (v) gather and present statistics for each individual user.

3.3.1.1 Multimedia output

Multimodal means of content representation was an interesting requirement, due to the variety of preferences and skills of children with cognitive impairments. To that end, three modes of information representation should be available in parallel: textual, audio, and graphical. However, each representation mode should be able to display the information adequately by its own. The educator should be able to customize the system, by selecting specific content representation media, in order to achieve the best possible information perception by the student. Configuration of modalities should be easily and quickly achievable any time during the interaction.

3.3.1.2 Individual user profiles

Each student should be uniquely recognized by the system, aiming to offer history and statistics data about the students' progress, as well as an appropriate system personalization to the user's preferences. The student will sign in the system by placing a unique card on the table's surface. The system, after a short welcoming, will provide brief information on the user's interaction history, including the total completed games and the success rate in each game. The educator can choose to continue a previous played exercise, repeat an already completed one, or start a new game. Initially, all students should begin their interaction at the simpler level of each game and switching between the simple and advanced level will be possible at any time by teacher's intervention. A preferred level may be set separately for each game, or for the entire system.

3.3.1.3 Customization

Customization of the various game parameters (e.g., difficulty level, font size, audio volume) to each individual student should be possible through user profiles. The custom settings and representation preferences of each registered user should be adopted automatically by the system upon signing in.

3.3.1.4 Context-sensitive help

A typical CocinAR session includes an educator who assists and guides the child while playing; however, the games should be easily playable with minimal supervision. To accomplish that, each game should provide appropriate context-sensitive help, which should be easily accessible by the student.

3.3.1.5 Statistics

The system should record statistic information about the student’s interaction history, for instance which recipes have been successfully completed, how many times a game was played and the student’s overall progress. Detailed statistics on a student’s progress will also be provided, for instance the specific dates and performance for each game session, as well as the nature and number of mistakes committed, or the number of help requests in each exercise.

3.3.2 GAMES’ SPECIFICATION

The system’s specifications with respect to the targeted teaching goals were also defined in collaboration with the RC’s educators. In general, the system should include a variety of exercises and mini games, aiming to instruct children: (i) which meals are appropriate for breakfast, lunch, and dinner, (ii) how to cook simple meals (e.g., bread with butter and honey, lettuce salad, pasta with tomato sauce, etc.), and (iii) fundamental rules of safety and hygiene that should be applied during the food preparation process. The requirements analysis and evaluation resulted in the specification of the following five games:

3.3.2.1 Meal appropriateness

The aim of this exercise is to train the students into making appropriate choices when it comes to deciding what to cook for breakfast, lunch, supper, and dinner. The trainee is requested to answer five questions, selecting which of the proposed meals are suitable for a given time of the day.

Difficulty levels	Two levels of difficulty should be provided, applied for each student. SIMPLE: Five multiple-choice questions, according to which the student has to select the correct answer among two available options. ADVANCED: Five multiple-choice questions, according to which the student has to select the correct answer among three available options. More than one options may be correct.
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Interaction	<p>CORRECT ANSWER: For each correct answer the system should provide both visual and auditory reward through appropriate graphic components.</p> <p>WRONG ANSWER: For each mistake, there should be suitable visual and audio feedback.</p>
Help	In the easy level the correct answer should be highlighted. In the advanced level, a wrong answer should be initially excluded and if the user asks for a second help, the correct answer should be highlighted.
Statistics Information	For each student, information regarding the total score per exercise and the number of help requests should be recorded.
Content	A list of appropriate meals for each time of day, corresponding to the ones taught in the RC, should be provided by the RC's educators.

3.3.2.2 Let's cook

This game focuses on teaching the meal preparation process to children with cognitive impairments.

The game begins with the educator assigning a recipe to the student. The selection may depend on the student's previous experience on this particular recipe or the amount of recipes successfully completed, information provided by the system. The selected recipe should be presented to the student via text, images and sound while the complete recipe should be available in a virtual "cook book".

For the recipe execution, the steps should appear sequentially with clear instructions, however the student should be able to go through the entire recipe any time during the interaction. At each recipe step, the student is expected to perform a simple task (e.g., place a slice of bread in the plate) and when this task is successfully completed, the recipe should move on to the next step. The educator should be able to force-move to the next step if he considers the step adequately performed with respect to the current teaching goal. This exercise is expected to be executed under the teacher's supervision.

Difficulty levels	<p>Two levels of difficulty should be provided, applied for each student.</p> <p>SIMPLE: Includes a subset of the complete recipe's set, consisting of elementary recipes with small number of steps and no use of complex tasks such as "cutting the onion".</p> <p>ADVANCED: Includes the complete recipe's set.</p>
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Interaction	<p>CORRECT ANSWER: For each correctly executed step, the system should provide both visual and auditory reward through appropriate graphic components.</p> <p>WRONG ANSWER: For each mistake, there should be suitable visual and audio feedback.</p>
Help	Context-aware help should be provided, depending on the current step the student is performing (e.g., audio prompt “place the lettuce card on the table”).
Statistics Information	For each student, information regarding the total score in the game, the total score per recipe and the number of help requests should be recorded.
Content	At least twenty recipes should comprise the system, whose detailed steps and their categorization into levels of difficulty will be provided by the RC’s educators.

3.3.2.3 Collect the ingredients

The aim of this game is to test the students’ comprehension of the basic ingredients required for the preparation of a specific recipe.

The game begins with the educator selecting a recipe, for which the student must collect all the appropriate ingredients. The teacher’s decision as to which recipe should be played can be facilitated by the system, which should provide information about the student’s previous experience with this particular recipe in the “Let’s cook” game (section 3.3.2.2) as well as the rest of the recipes completed in this game.

The key requirement of this exercise is to select all the necessary ingredients for the preparation of a given meal. Only when all the correct ingredients are collected the system should move automatically to the next exercise, unless the transition occurs by teacher’s intervention.

Difficulty levels	<p>Two levels of difficulty should be provided, applied for each student.</p> <p>SIMPLE: A list with of ingredients – both correct and incorrect - should be provided and the user must point out only the correct ones by selecting representative cards.</p> <p>ADVANCED: The student must find the correct ingredients by placing their representative cards on the table.</p>
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Interaction	<p>CORRECT ANSWER: For each correct answer, the system should provide both visual and auditory reward through appropriate graphic components.</p> <p>WRONG ANSWER: For each mistake, there should be suitable visual and audio feedback.</p>
Help	At first, a list of the recipe’s steps should be provided to the student as a reminder. If additional help is needed, one of the correct ingredients should be highlighted, while as a final help, the system will suggest a correct ingredient.
Statistics Information	For each student, information regarding the total score in the game, the total score per recipe and the number of help requests should be recorded.
Content	At least twenty recipes should comprise the system, whose detailed steps along with the ingredients needed for their completion and their categorization into levels of difficulty will be provided by the RC’s educators.

3.3.2.4 Collect the utensils

The aim of this game is to test the students’ comprehension of the basic utensils and tools necessary for the preparation of a specific recipe.

The game begins with the educator selecting a recipe, for which the student must collect all the appropriate utensils and tools. The teacher’s decision as to which recipe to select to play with will be facilitated by the system, which should provide information about the student’s previous experience on this particular recipe in the “Let’s cook” game (see Section 3.3.2.2) as well as the rest of the recipes completed in this game.

The key requirement of this exercise is to select all the necessary tools used for the preparation of a given meal. The system moves automatically to the next exercise only when all the correct answers are selected, unless the transition occurs by teacher’s intervention.

Difficulty levels	<p>Two levels of difficulty should be provided, applied for each student.</p> <p>SIMPLE: A list of tools and utensils – including both correct and incorrect options, should be provided and the user must point out only the correct ones by selecting the corresponding cards.</p> <p>ADVANCED: The student must find the correct tools and utensils by placing their representative cards on the table.</p>
Interaction	CORRECT ANSWER: For each correct answer, the system should provide both visual and auditory reward through appropriate graphic components.

	WRONG ANSWER: For each mistake, there should be suitable visual and audio feedback.
Help	At first, a list of the recipe’s steps should be provided to the student as a reminder. If additional help is needed, one of the correct answers should be highlighted, while as a final help, the system should suggest a correct tool or utensil.
Statistics Information	For each student, information regarding the total score in the game, the total score per recipe and the number of help requests should be recorded.
Content	At least twenty recipes should comprise the system, whose detailed steps along with the tools and utensils needed for their completion and their categorization into levels of difficulty will be provided by the RC’s educators.

3.3.2.5 Safety and hygiene rules

This game focuses on training the students on fundamental rules of safety and hygiene that should be applied during the food preparation process. Pairs of right and wrong behaviors should be presented to the student, who will have to point out the correct one, by selecting the appropriate card.

Difficulty levels	Both difficulty levels should include the same questions.
Interaction	CORRECT ANSWER: For each correct answer, the system should provide both visual and auditory reward through appropriate graphic components. WRONG ANSWER: For each mistake, there should be suitable visual and audio feedback.
Help	When a student asks for help, hints on the correct answer should be provided by the system.
Statistics Information	For each student, information regarding the total score in the game, the total score per question and the number of help requests asked should be recorded.
Content	The content should consist of pairs of correct and wrong behaviors, provided by the RC’s educators (shown in Table 1).

CORRECT BEHAVIORS	WRONG BEHAVIORS
1. I wash my hands before cooking	I cook with dirty hands
2. I cut the meat and the vegetables in different cutting boards	I cut the meat and the vegetables in the same cutting board

3. I switch off the stove when I finish cooking	I don't switch off the stove when I finish cooking
4. I turn off the toaster when the toast is ready	I don't turn off the toaster when the toast is ready
5. I throw away the rubbish	I leave the rubbish on the kitchen counter
6. I clean the kitchen counter after cooking	I leave the kitchen counter dirty after cooking
7. I clean the fruits and vegetables before eating them	I eat the fruits and vegetables directly from the fridge
8. I clean the meat before cooking it	I put the meat inside the pot without washing it
9. I wash my hands after going to the bathroom	I don't wash my hands after going to the bathroom
10. I cough away of the food putting my hands in front of my mouth	I cough over the food
11. I remove all jewelry from my hands	I cook wearing my jewelry
12. I wash my hands after touching my nose	I don't wash my hands after touching my nose
13. I don't touch the kitchen stoves	I touch the kitchen stoves
14. I keep knives and other sharp objects away from the other people	I go near other people with the knife or other sharp objects on my hands

Table 1. The pairs of correct and wrong behaviors provided by the RC's educators.

3.4 NON-FUNCTIONAL REQUIREMENTS

This section reports the non-functional requirements identified for the design of CocinAR, as they occurred according to the defined user characteristics, or as directly provided by the RC educators stemming from their experience.

A category of requirements refers to the graphic representation of kitchen objects, applications and notions. An important deduction was that the system's interface should be simple and intuitive and the graphics simple, without many details and information. That way, the cognitive load imposed upon the children decreases significantly. Moreover, the images of the various objects (ingredients, utensils etc.) depicted both in the system's virtual interface and on the physical cards, should be as representative as possible to assure students' understanding of the represented notions. Regarding color selection, they should be bright and with adequate contrast, yet not tiring. According to the RC educators, overly vivid colors can be tiring for their students. Furthermore, since common visual problems include difficulties in reading small size fonts, all text should be presented in large font, allowing also its further customization. As a result, all instructions and information provided by the system in text format should be presented using distinct and size-customizable fonts, while the colors should be bright and with adequate background-foreground contrast but not too intense.

An important requirement was that two content levels should be available to accommodate the needs of students with lower and higher functionality: a simple one for students with severe cognitive problems and a more advanced one. In more details, the simple content should consist of more plain, flat images, deprived from shadows and blended colors. Moreover, an alternative version of all text elements should be available in this mode, facilitating children with limited reading skills.

The movement restrictions of our users was another important concern. Upper limb mobility varies in children with cognitive impairments, therefore all interactive areas should be large enough and placed appropriately to accommodate a wide range of manual dexterity levels. Another requirement is that all printed material used (e.g., cards), should be waterproof and tolerant to misuse, since the movements and actions of our users may sometimes be involuntary and therefore, unpredictable. For the same reason, the overall construction of the system should be steady and sturdy to guarantee a safe and trusty environment even under unforeseen circumstances. Furthermore, it is possible that some users may have lower limb mobility impairments, so the system's physical structure should accommodate usage by wheelchair users.

Another requirement stemming from the analysis is that short phrases are better comprehended by children with cognitive impairments, so simple and direct language should be preferred for the system. Therefore, all instructions and feedback provided by the system should also be available in short, coherent phrases. For instance, the feedback for a student's wrong answer will be "Try again" rather than "Your answer was wrong! Please, try again". Respectively, the feedback for a correct answer will be the phrase "Well done!". In order to ensure the appropriateness of text, all the text that would be incorporated in the system should be first assessed by the RC educators.

Finally, regarding the content of the system, RC educators provided specific requirements as to which recipes the game should include, the particular characteristics each recipe should comprise and what exercises should be included in the system, as described in the functional requirements section.

4 SYSTEM DESIGN

Designing augmented reality games may be a challenge when it comes to facilitating seamless interaction with the virtual components using real objects. More importantly, when the game’s target users are children with cognitive impairments, design gets even more challenging. For that reason, designing this kind of games requires the collaboration of special education teachers, User Experience (UX) experts, designers and programmers.

The design and implementation of the CocinAR system has followed an iterative approach, involving multiple evaluations, as shown in Figure 2. The whole design process was conducted in close collaboration with educators of the Rehabilitation Center and was a continuous and multi-step task. In more details, following the specification of the functional and non-functional requirements (see Section 3) a detailed design was produced for the system, which was again evaluated by the Rehabilitation Centre educators. Following, a demo was implemented as a vertical prototype, featuring half of the provided functionality. The demonstration implementation was followed by an evaluation experiment involving children with cognitive impairments who visit the Centre for rehabilitation (Section 6.1), with the aim to assess the produced designs as well as the various interaction modalities and system setups described in Section 4.3.3. Based on the results of the evaluation, the system was refined and installed at the Center for pilot use, while at the same time the entire functionality of the system was implemented. Finally, after installing the fully implemented CocinAR system, a user-based evaluation was carried out (Section 6.2).

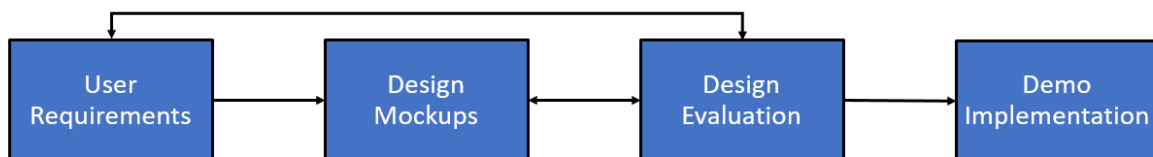


Figure 2. The design process of the CocinAR system.

4.1 DESIGN OF THE AUGMENTED SPACE

An important concern that directed the physical design of the system was that it should “blend in” the Rehabilitation Center’s kitchen, where children with cognitive impairments are actually practicing their cooking skills in the context of independent living classes. In this manner, children will be able to directly associate the knowledge they acquire from the system with the actual cooking process, while educators will have the flexibility to easily transition from the virtual environment to the physical one and allow children to actually cook the meals.

The CocinAR system consists of a computer, a high-resolution projector, a simple wooden table, an infrared camera and a high-resolution camera. The system is designed to “camouflage” itself in a way that none of the equipment used is visible to the users. This is achieved by hiding the hardware equipment inside a kitchen board, leaving visible only the plain wooden table, with the aim to support an immersive user experience (Figure 3).

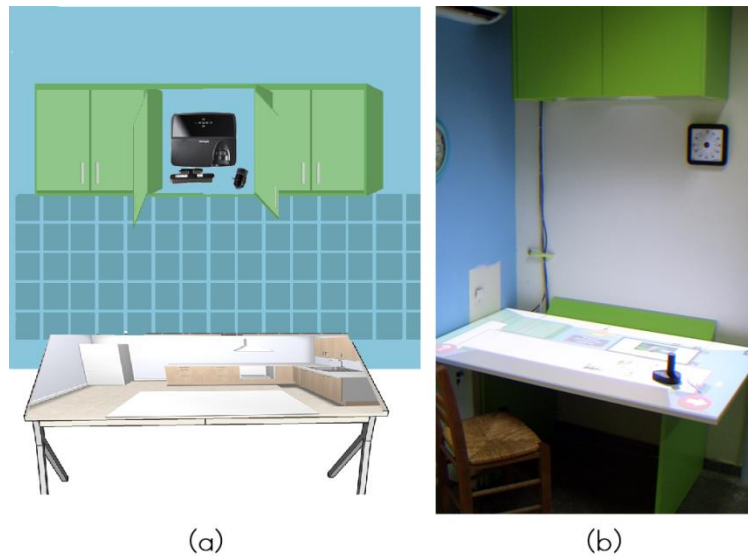


Figure 3. (a) a representation of the system setup, (b) the actual setup at the Rehabilitation Center.

Sticking to this immersive approach, interaction with the CocinAR system moves beyond traditional keyboard and mouse interaction. According to Section 2.4 tangible interaction stimulates multiple senses and promotes the development of cognitive functions, so interaction via physical, tangible objects was preferred for the system over a touch approach. Firstly, the user interacts with simple printed cards, which, once on the table, are tracked by the high-resolution camera using computer vision algorithms. Plasticized paper cards were chosen as an appropriate material in this case, due to their tolerance to mismanagement, scalability (easy to create new cards) and low replacement cost. Additionally, an infrared stylus is used to produce mouse-click equivalent functionality when pressed against the table. Last but not least, in collaboration with the Rehabilitation Center’s experts, a custom infrared pointing device was designed for children with motor difficulties in order to facilitate an easier and more comfortable interaction with the system. This custom device, which we refer to as “stamp” is described in more detail in the next section.

4.2 DESIGN OF THE POINTING DEVICE (STAMP)

Aiming to support children with reduced motor skills, a custom IR 3D printed stamp that supports wireless charging (Figure 4) has been designed, through which students can "tap" on virtual interactive elements. Internally it features a pressure-sensitive bottom surface which, when pressed, lights up the infrared LED mounted on its topside. Whenever that happens, the computer vision subsystem that monitors the table's surface through the infrared camera (Figure 3) propagates a simulated mouse event back to the main game. However, the innovative feature of the stamp is its physical design rather than its functionality, as similar devices can be found in the market.

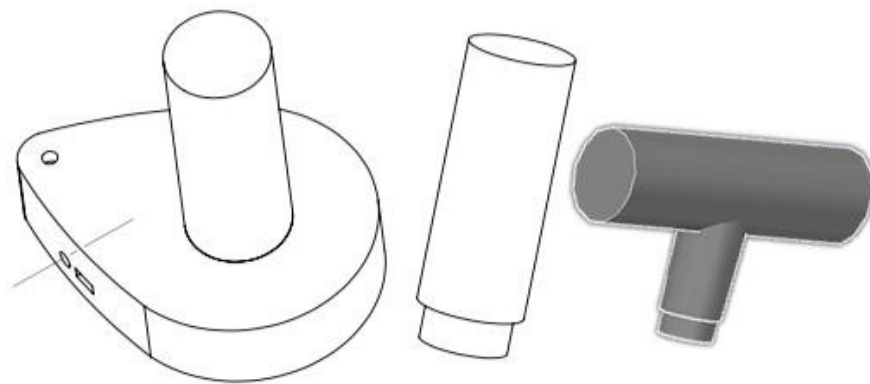


Figure 4. A 3D reconstruction of the stamp and its different handles

Its physical design employs many of Norman's rules for designing good and usable everyday things [94] in order to accommodate the special needs of the target user group. In terms of materials, the stamp's main body is made of lightweight plastic, while its bottom side is covered with rubber to satisfy a threefold purpose: (a) increased friction to discourage dragging, (b) minimized noise generation when "hitting" the desk and (c) increased durability. As regards its appearance, its exterior shape features a "pointy" design to implicitly guide the user where to direct the light, while the embedded handle contributes to its stamp-like look and enhances the natural relationship that couples function and control: while holding it a user can only "stamp" interactive elements. To ensure its usability across a wide range of students, three different handles were built to accommodate different grip sizes (i.e., small, medium, large), while a fourth option is available for students with motor disabilities, where the handle can be removed and the stamp can be strapped on the student's palm.

4.3 THE DESIGN PROCESS

The design and implementation of the CocinAR system was a continuous and multi-step process, involving multiple design adaptations and evaluation sessions with both UX experts and educators from the Rehabilitation Center. The initial design was based on the requirements analysis described in Chapter 3, according to which the system should, amongst others:

- Incorporate games, which will introduce the students to three different teaching goals: (i) which meals are appropriate for breakfast, lunch, and dinner, (ii) how to cook simple meals and (iii) fundamental rules of safety and hygiene that should be applied during the food preparation process
- Provide two difficulty levels for each game
- Support content representation through audio, images and text, concurrently if necessary
- Offer context-sensitive help in every game.

Next, we will present indicative mockups of the four design iterations.

4.3.1 INITIAL DESIGN

The first home screen prototype, shown in Figure 5, includes five games: (i) “When do we eat the food?”, (ii) “Let’s cook”, (iii) “What ingredients do we need?”, (iv) “What pottery do we need?” and (v) “Rules of hygiene”. The levels appear on the top right corner of the screen and the navigation between the various screens is achieved from the top-left corner. Figure 5 (b) depicts a first prototype of the multiple-choice game “When do we eat the food?”. The content representation options are available at the top right corner and the user can navigate sequentially through the questions via the right and left arrows. Help is



Figure 5. Sample of the first mockups. (a) The home screen includes five games options, navigation arrows and the student levels. (b) the interface for the “when do we eat the food” game, which also offers the audio, text and image content representation options, with the representation via images currently selected.

provided pressing the question-mark button and a counter informs the user about the exercise’s progress. The user selects the correct answers amongst three options and then proceeds to the next question. This initial design constituted the basis for all the subsequent improved versions. The prototypes’ evaluation from UX evaluation experts gave prominence to the need of major design changes, described in the next section.

4.3.2 REFINED DESIGN

Several striking observations were made by the evaluation experts, drastically changing the system’s look and feel (Figure 6). The first and main observation was that the interface was unnecessarily cluttered. To address this issue, the background image was removed and images that are more coherent were used. Additionally, an alternative flat graphic design, which would use simple, two-colored images and flat icons was considered necessary to support children with visual difficulties. Another remark was that the teacher’s controls were scattered along the top of the screen obstructing the teacher’s natural flow of interaction. To address this problem, the teacher’s menu was fully redesigned, gathering all the available options on the right side of the table, where the teacher will normally stand. One more design element the evaluators found confusing was the levels presentation, on the grounds that it was difficult for them to distinguish which one was currently selected. This issue was resolved by depicting the user’s level as a single button, which, once tapped upon, switches value. Apart from these design changes, the initial design was also expanded to illustrate additional options in the teacher menu, such as the system settings, the name of the current user and a link to the current user’s statistics.

The updated home screen version was once more evaluated by UX evaluators, in terms of usability and accessibility. The first full system design prototypes were based on this evaluation’s observations and comments.



Figure 6. Two versions of the updated home screen prototypes. (a) the menu using full graphics (b) the alternative menu showing only basic outline images and flat icons.

4.3.3 FULL DESIGN – BETA PROTOTYPE

The last evaluation conducted by UX experts resulted in sufficient feedback for a complete design to be developed and evaluated by the Rehabilitation Center’s educators. In this Section the complete system design in its first version will be described.

4.3.3.1 Design for teacher vs Design for student

The fundamental observation of this evaluation was that the children using the system may be of various ages and functionality, therefore their reach may prolong to a limited area. In that case, a vertically aligned menu would be an unsuitable choice, because the interactive elements at the top of the table would be unreachable to some of the children. To accommodate this, all the interactive elements that might interest children were confined in the bottom half of the table surface, close to where the student is seated (Figure 7).



Figure 7. The home screen layout. The games are displayed in a horizontal layout, in a child-friendly reaching area, while the teacher’s menu is moved at the top right corner. In (b) the teacher’s card appeared revealing statistic information for each game, and the alternative, simpler menu style is activated.

On the other hand, all the teacher-related elements lay at the top half of the table, removing any unnecessary cognitive load from the student. In Figure 7 it can be noticed that the teacher’s menu is moved at the top right corner and the options are depicted in a more compact form. In more details, the student level is transformed into a single switching button and the content representation options are depicted through simple on/off icons. The last three icons represent the history, settings and logout option respectively. In addition, some visual elements are visible on demand and can be hidden to avoid student’s distraction. The additional content may consist of teacher assisting information, game options, system configuration options, statistic information, etc., depending on the current system screen, and it appears when a special card - the “teacher-card” - is placed on the table (e.g. Figure 7, Figure 11 (c), Figure

10). This user-oriented separation of the functionality allows children’s undistracted and natural interaction, while facilitating the discreet intervention of the teacher when necessary.

4.3.3.2 Personalized Content Visualization

In order to accommodate the variety of preferences and dexterities of the target user group, CocinAR was designed to support personalization in terms of content presentation, interaction style (Section 4.2), form of feedback and difficulty level, as described in the analysis of functional requirements (Section 3.3). In more details, the content representation options supported are the following:

- a) **Text:** All text elements can be configurable to appear in customizable font size depending on the visual preferences of the player. In addition, to support children with limited reading skills who may recognize short phrases or individual words but not complete sentences, an alternative simplified version of each text element is available. Finally, all text elements can disappear to prevent confusion for students with no reading skills.
- b) **Images:** Our users’ reading skills may vary from excellent to minimum, so “CocinAR” is designed to support text-to-symbol conversion. Symbols are images representing objects, actions or states and are used by children of the Rehabilitation Center with minimum or no reading skills during their daily lessons and activities. One of the most eminent symbol languages is the Makaton vocabulary described in [43]. If chosen, all text elements will convert to this symbol language, even at runtime. Additionally, since some of the users may suffer from mild visual impairments, all the images used in the system can be replaced by a simpler version.
- c) **Audio:** According to the users’ requirements analysis, all children can successfully understand text when it is read aloud, especially if the reading rate is appropriate and the text language is simple. Taking that into consideration, every instruction or feedback given by the system is also pronounced by a text-to-speech service, as happens with all text elements, once tapped on. The text-to-speech is also fully customizable, supporting three different speech speed rates, allowing volume adaptation as well as complete deactivation. Sound effects can also be activated to provide additional feedback mainly for distinguishing correct from wrong answers.

All of the aforementioned configurations can be set at runtime from the system’s settings page shown in Figure 8 via the teacher’s menu at the top right corner. In the teacher’s menu, we notice that the settings option is highlighted and two navigation buttons have appeared, one to move directly to the home screen and the second to move to the previous page. These buttons are visible in all system’s pages except from the home page.

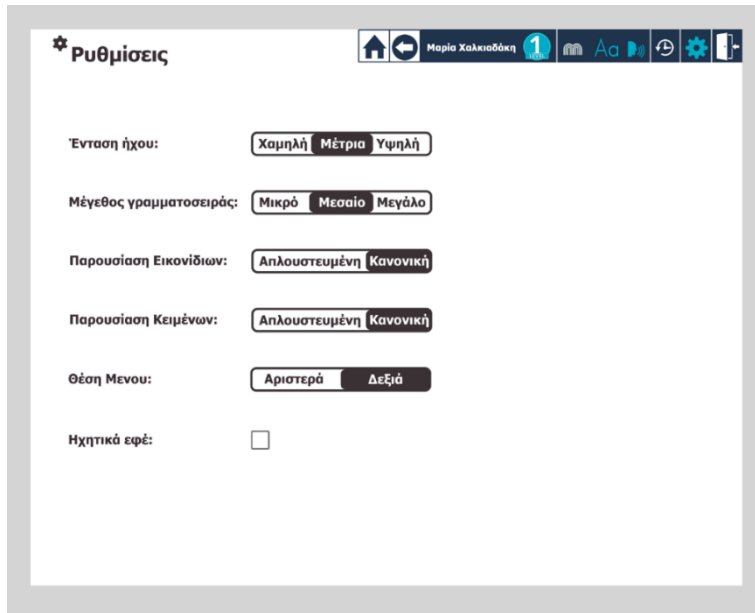


Figure 8. The system page with the settings: speech volume, font size, text and image complexity, the top menu's position and the activation of sound effects. The top menu can appear on the left or on the right side of the table, depending on the teacher's standing position.

An example of content provision personalization is depicted in Figure 9. The “when do we eat it?” game in (a) appears in text and audio mode, while in (b) the user prefers symbol language, so the text is removed from the answer options and the question consists of symbols instead of words.

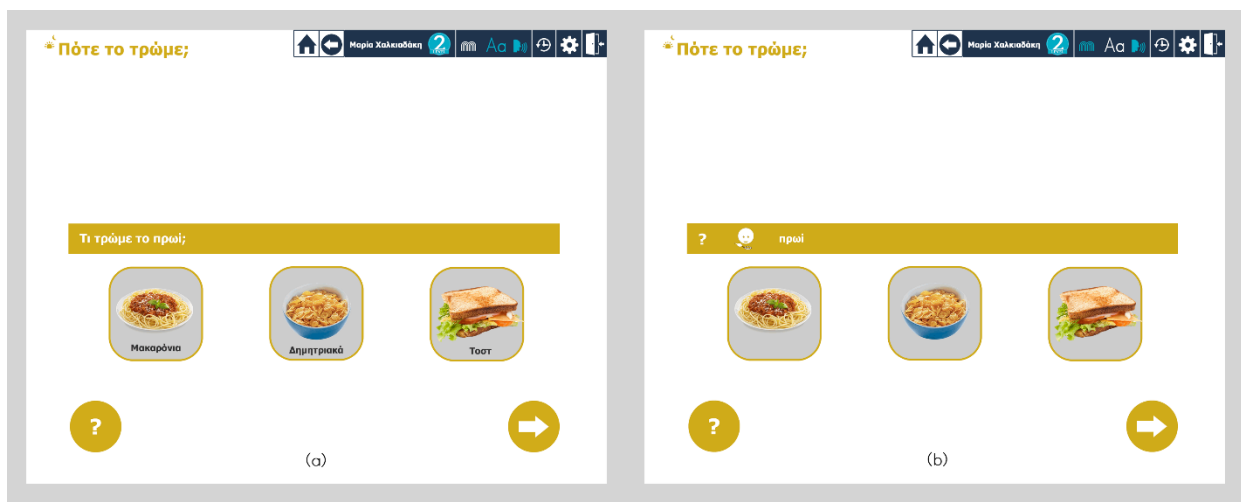


Figure 9. Two different content representation modes (a) the text and audio representation, (b) symbol language with audio.

4.3.3.3 The Recipes Menu

For a recipe-centered game to start (“Let’s cook”, “Find the ingredients” or “Find the utensils”), the teacher assigns a recipe to the student, according to the current teaching goal and the student’s level. A recipes’ menu page includes all the recipes, which were provided by the Rehabilitation Center’s experts. The presentation of all the available recipes in a structured, informative but also uncluttered way was quite a challenge since there was a substantial amount of information to be displayed. For each recipe, the name with a representative picture should be visible by the student, while history information for each recipe should be available for the teacher. The teacher-directed content includes for each recipe the last session’s date and score, as well as the games that have been played with this recipe (Figure 10 (b)).

The design depicted in Figure 10 addresses the above challenge by presenting the recipes as “blocks”, which contain the food’s image and name while the aforementioned teacher-oriented information (Figure 10 (b)) is available via the teacher card. Once tapping on a recipe and provided that the audio is activated, the name of the recipe is announced and after a short waiting time, indicated by a loading wheel timer, the recipe is selected and the game begins. The timer was chosen as an appropriate design solution for error avoidance (so a recipe would not be selected by mistapping) and for allowing the student to listen to the recipe’s name before actually selecting it.



Figure 10. The recipe’s menu (a) simple version for student use, (b) with the teacher’s extra information activated.

4.3.3.4 The Multiple-choice Games

The multiple choice or “mini” games were designed to enhance and evaluate the knowledge obtained during the “Let’s cook” game. The multiple choice form bestows a hidden “test” character to these games, so the teacher can obtain valuable feedback on students’ difficulties while the child is having fun. All the exercises and mini games of the CocinAR system follow common design principles, offering consistency and uniformity throughout the system. To support children with visual difficulties, CocinAR employs a minimalistic approach to graphic design, with distinct elements and high contrast colors (Figure 11).

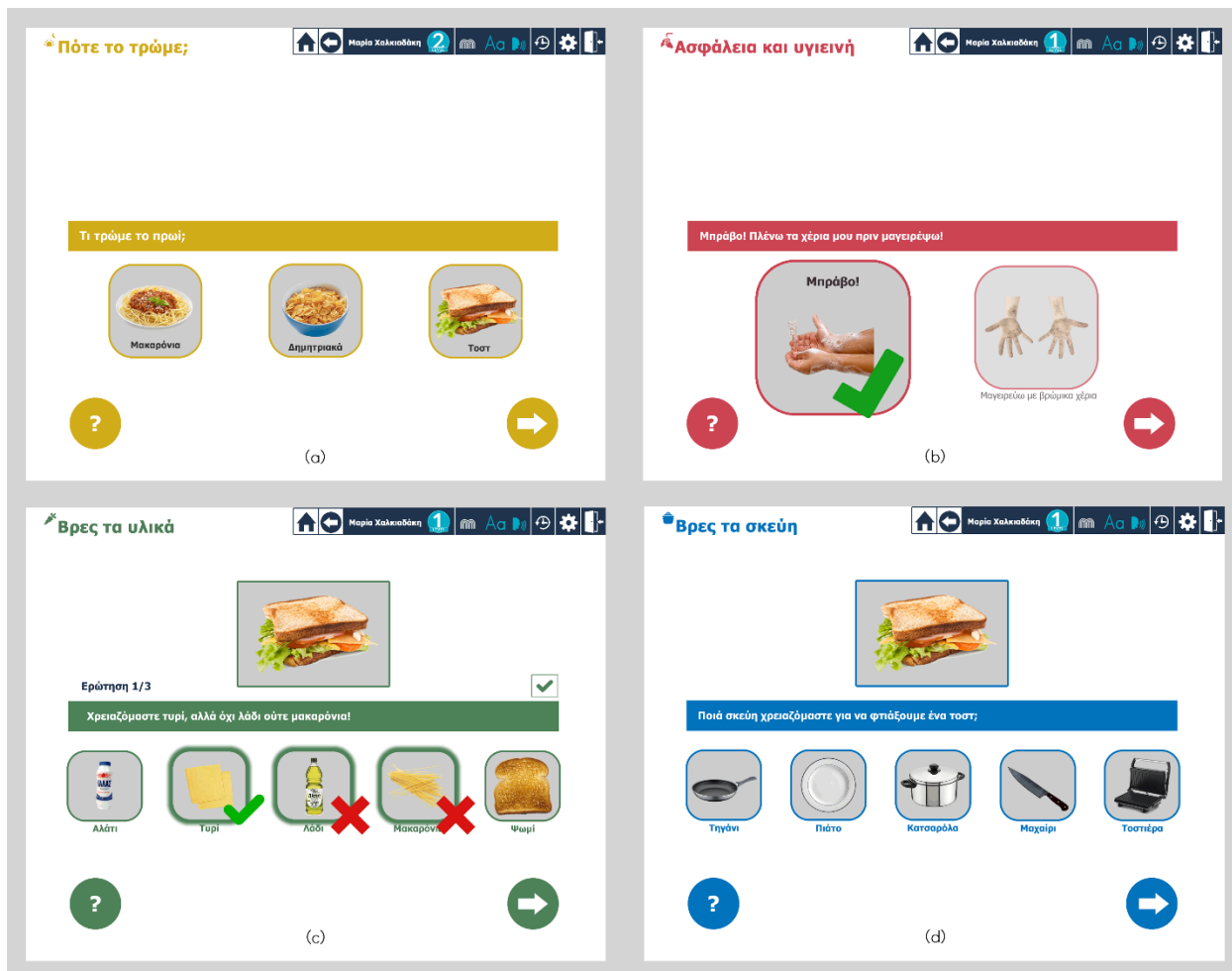


Figure 11. The four multiple-choice games. (a) “when do we eat it?” (b) “Safety and hygiene rules”, (c) “Find the ingredients” and (d) “Find the utensils”. In (b) the student has answered correctly that we should wash our hands before cooking and in (c) the student has answered that we need cheese, olive oil and spaghetti to make a sandwich and relevant feedback has appeared.

The multiple-choice options are simple, square images with a text description underneath. When a student taps on an option, its description is read aloud and the border gets thicker, indicating that this option is selected. An option can be unselected by re-tapping on it. Help is available anytime by tapping the bottom left question mark button. Each time a student asks for help, one of the wrong options remaining fades out and auditory help is provided. When the student is ready, he or she taps on the arrow

at the bottom right corner, the selected answers are checked and feedback is provided. Game-flow options appear above the question with the use of the teacher-card as depicted in Figure 11 (c).

Feedback is presented with simple visual and auditory messages. The question text is replaced by the answer's result feedback while, after the appropriate sound effect, the text to speech service announces the result. In addition, distinct graphic remarks appear for each option selected indicating its correctness, as shown in Figure 11 (c).

The second level of the "Find the Ingredients" and "Find the Utensils" games requires the user to choose the correct answers from a superset of cards and place them on the table (Figure 12 (b)). For this kind of questions, a "basket" metaphor was followed for two reasons. First, it would be easier for the children to understand which cards have been chosen if they are gathered inside a limited area. The second reason was that the students usually spread all the available cards in front of them in order to choose the correct ones, so it would be disturbing if all these cards were recognized by the system. Therefore, card recognition is confined inside the signified area. Feedback for each card is projected on top of the physical cards once the student is ready, by tapping on the arrow button.

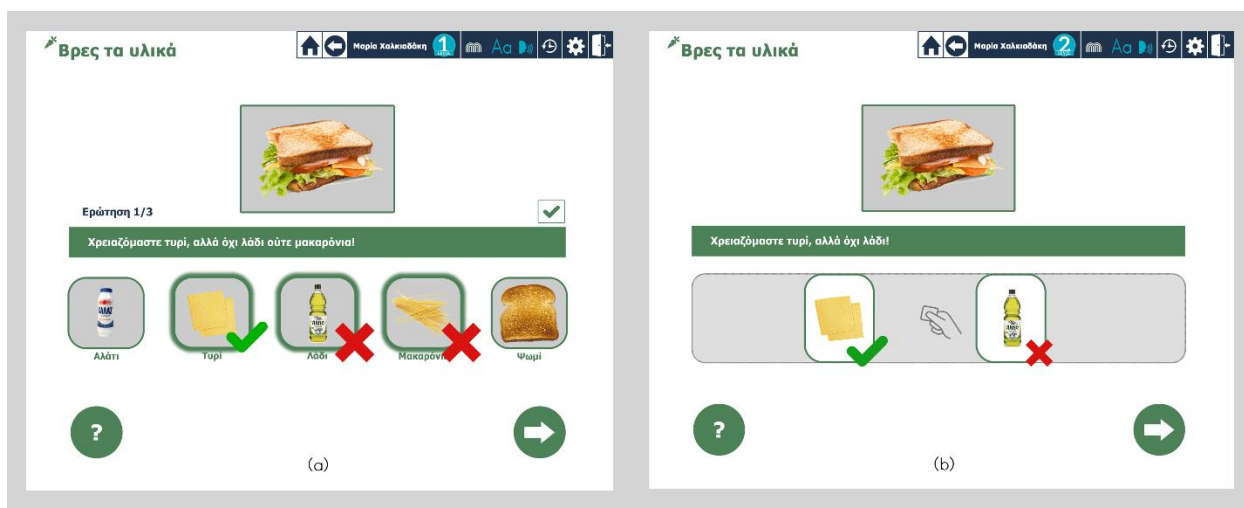


Figure 12. (a) The first level of the "Find the ingredients" game, right after a student's answer. (b) The second level of the "Find the ingredients" game, at the same time.

4.3.3.5 The “Let’s cook” Game

The virtual kitchen, as shown in Figure 13, has the form of an actual kitchen, accommodating a sink, an oven with stoves, a trashcan and a table. These kitchen appliances are the points of interest, the interactive parts of the kitchen, which we will refer to as “slots”. Slots are the positions where the virtual ingredients and utensils appear and can be manipulated using the stamp. Following the basic system’s design principle, they are all deliberately confined at the bottom half of the table, so that they are easily reachable by small children.

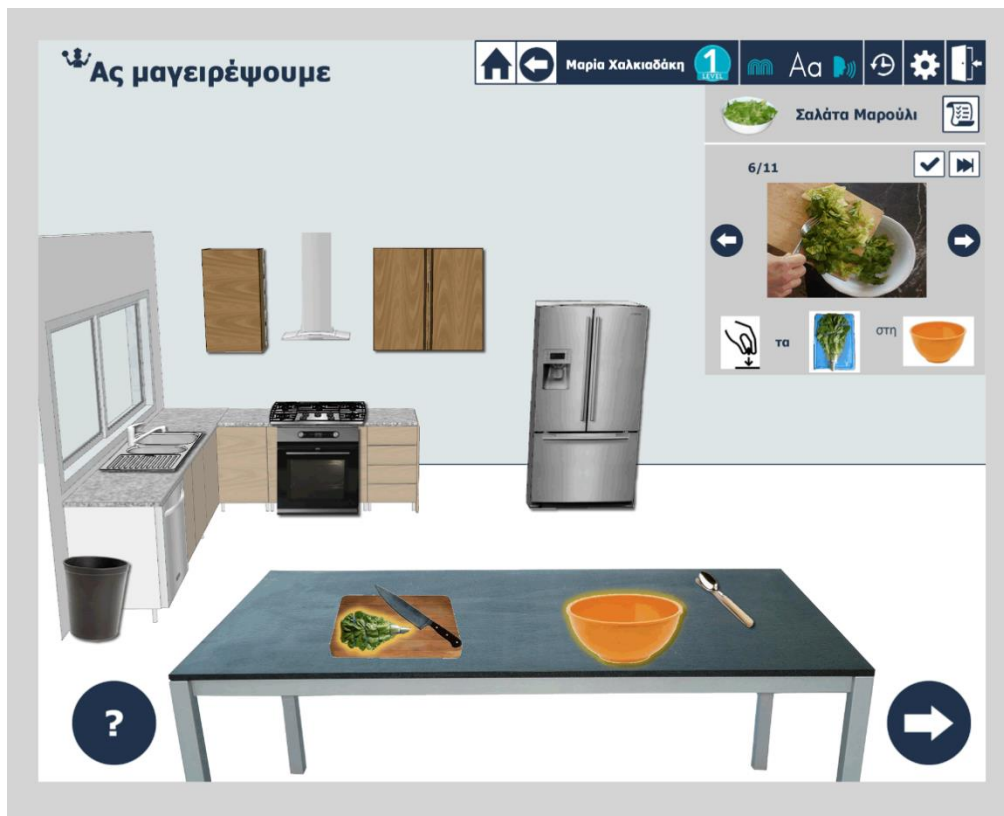


Figure 13. The virtual kitchen’s interface. The current step “put the lettuce in the bowl” expects the student to tap on the lettuce and then on the bowl. Currently, the help button is pressed and the components to be tapped are highlighted.

The recipe steps appear sequentially at the top right corner of the virtual kitchen along with the teacher’s game flow options which were suggested by the Rehabilitation Center’s teachers. The current step’s instruction can be shown either through regular text or symbolic language, which replaces text words with explanatory images.

The game-flow options consist of discreet buttons which facilitate teacher's intervention during the step execution. More specifically, these controls include a "skip" button, which can be used when the teacher considers a step to be optional (students may or may not want lettuce in their sandwich). Moreover, a "force correct" button is available to be used when a teacher believes that the step was completed satisfactory in relation to the current session's goal. Finally, the teacher can move to previous or next steps using the arrows, or choose to see all the steps of the recipe in a list, showing which have been completed and which not (Figure 14).

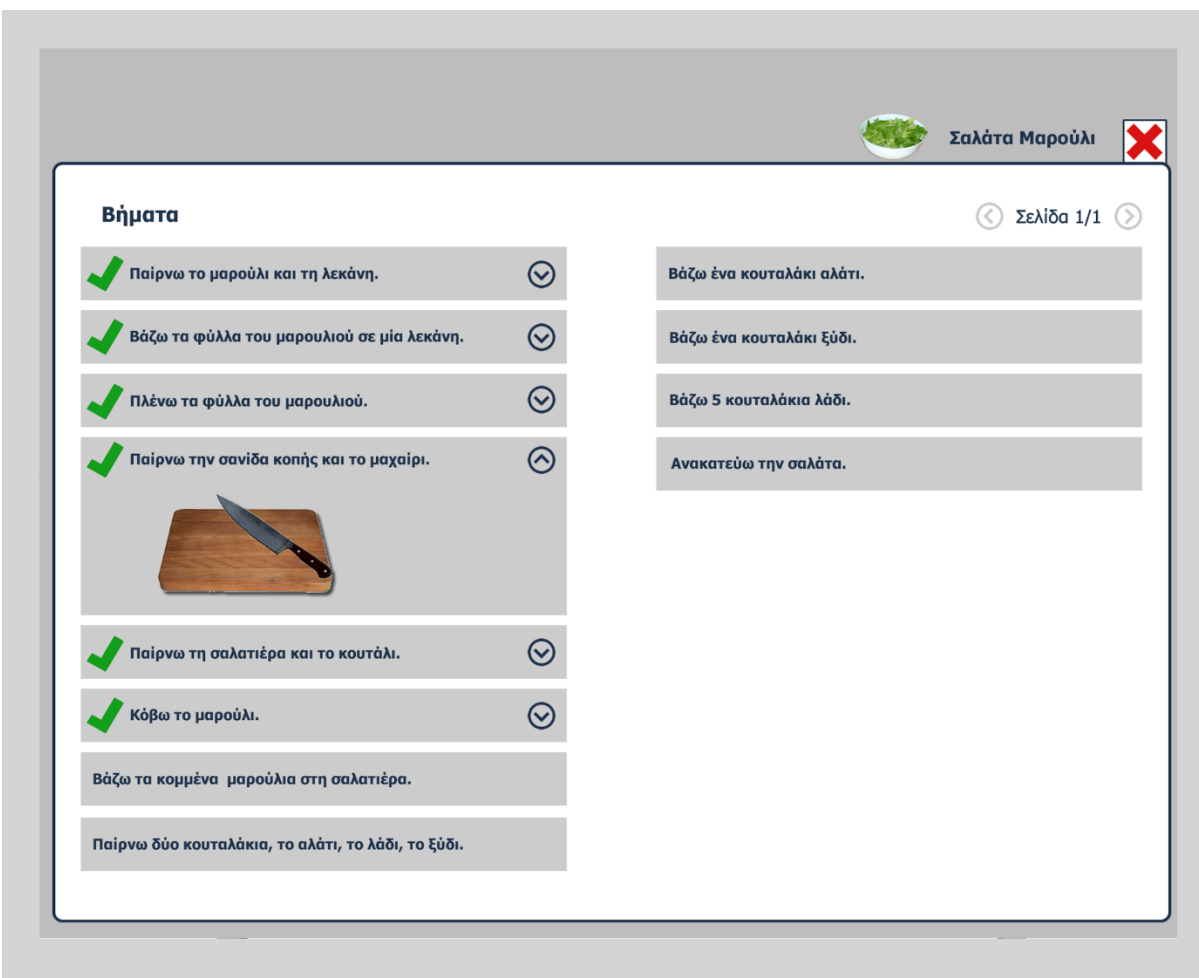


Figure 14. The steps list in a compact form. The completed steps are noted with a "tick" before the instruction. Each step can be expanded to reveal the step's descriptive image.

When playing the “Let’s cook” game, a student firstly collects the recipe’s ingredients by laying the respective physical cards on the table’s surface, and then combines them by interacting with their virtual counter-parts. Clearly, this process poses some unique requirements: during its first half the interaction mimics the physical actions that someone would perform in a real kitchen (e.g., to bring the cutting board and the knife on the table), while during its second half the user has to interact in a manner that would not disrupt the flow of the whole process. For the ingredients’ retrieval, a placeholder element appears on the table signifying that cards placed there will be recognized by the system (Figure 15), while for the interaction with the virtual counter-parts, students “tap” with the pointing device on the interactive elements (Figure 13).



Figure 15. An indicative utensil’s retrieval step. The student is expected to put the “knife” and the “cutting surface” cards in the “basket” as implied by the icon. We notice that from previous steps, the lettuce lays clean, next to the sink.

At the beginning of a recipe's step, the text-to-speech service announces the related instruction (e.g. "Take the cutting board and the knife", or "Put the lettuce in the bowl"). If the step asks for the retrieval of some ingredients or utensils, the student must find and place the correct cards in the cards' placeholder. Context-aware help is available to the student by tapping on the question-mark button at the bottom left corner (Figure 13). The answer is checked only when the user confirms the selected answer by tapping on the "arrow" at the bottom right corner. In case of wrong answer, the system provides advice about the step and encourages the student to try again. On the other hand, if the step was completed successfully, a clapping sound rewards the student and a video of an actual execution of this step in the real kitchen of the RC is played (Figure 16), where the step's picture is located. Before continuing to the next step, each card's virtual counter-part appears on the system's virtual table and is ready to be interacted with. The virtual components can be moved, combined, turned on and off, etc.

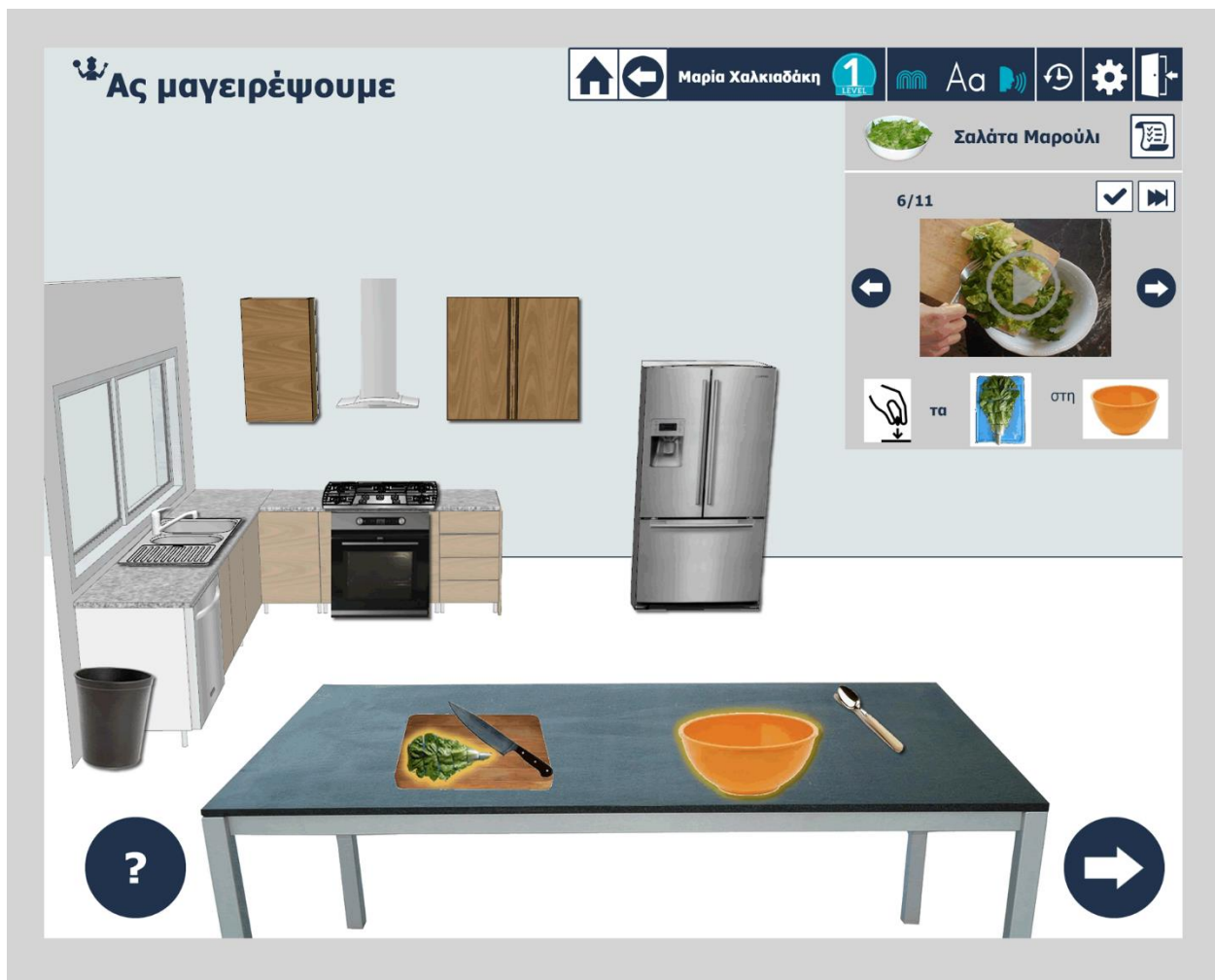


Figure 16. A video of putting lettuce inside the bowl is played where the image is located.

4.3.3.6 History & Statistics

According to the initial requirements of the Rehabilitation Center’s teachers, the system is designed to capture statistical data for every student, so that educators could obtain the complete picture of each child’s evolution through the sessions, in terms of both the quality of interaction with the system and the knowledge derived from it. To that end, a profiling functionality was designed, according to which various user preferences and interaction information are kept for every registered user.

The students are registered by their teachers through the system, creating a simple user profile. Once a user is logged in, the settings last used by the particular student are retrieved and applied, thus personalizing the system according to the current user’s preferences. In more details, the profile data for each student are the following:

- The student’s special identifier, which consists of a unique identification number for each student.
- The student’s profile information, which is the name, sex, date of birth and level of functionality.
- The current state of the student, that is if the student is currently an active or past student.
- The student’s personalization preferences, including the content representation options (symbol vs. text), the preference between simple and regular text, the audio or speech deactivation choice, the font size, the speed of speech rate, etc. The available personalization options have been described in more detail in Section 4.3.3.2.

Furthermore, the teacher can have access to game history information so that the strengths and weaknesses of each student are easily recognizable. Regarding the game history, the following data is collected:

- The number of times a game has been played.
- The date and the duration of each game session.
- The list of all the interactive elements that the user selected during the session.
- The number of times a student has asked for help in every game session, as well as how many times the “help” button has been tapped in every session and the specific step for which help has been asked.
- The number and description of all the wrong answers in a game session, in total or per step.
- A performance score calculated/derived from the number of help and mistake records for every game session.

An abstraction of the accumulated data is visible through the system, hiding unnecessary complexity and highlighting useful information. The data are available in two forms, per game and per recipe, giving teachers the ability to crosscheck information from different perspectives/angles when it comes to deciding about their next teaching goal. Basic and more general information is presented in the initial “history” screen (Figure 17), categorized per game on the left-hand side and per recipe on the right-hand.

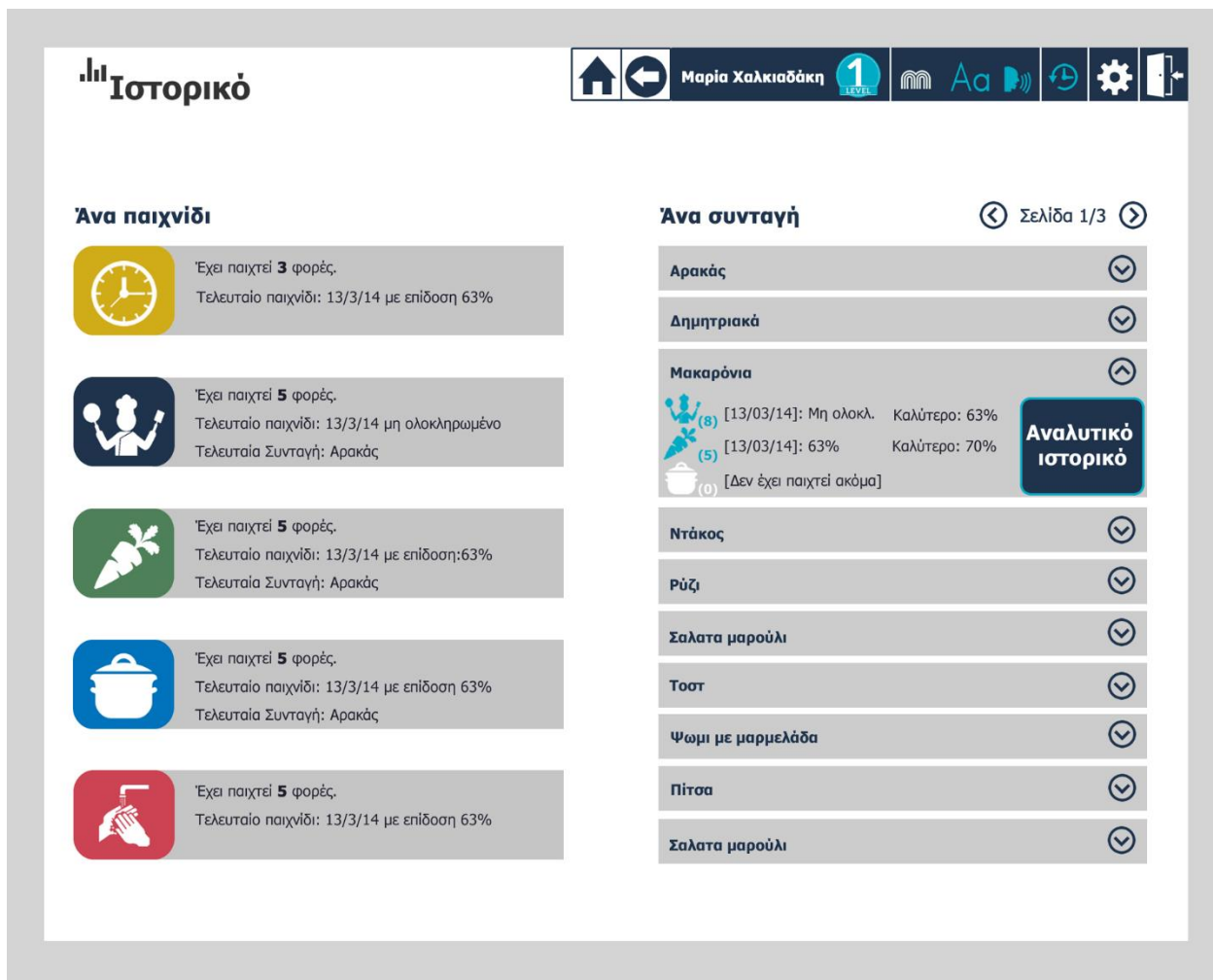


Figure 17. The basic statistical data available for each student

For each game, the system initially presents some basic information, offering a general feeling of the student's level of progress. The information requested by the Rehabilitation Center's experts towards this end is: (i) the number of times the game was completed, (ii) the date and performance of the last played game and (iii) wherever is applicable, the last recipe played. It is worth mentioning that, at this point, the game options' layout was designed as a vertical aligned menu based on two observations. Firstly, the adaptation of this layout style increased the space available for the proper information provision and secondly, there was no point in sticking to the child-oriented protocol, since the history functionality was intended only for the teachers.

More detailed data are available for each game separately, upon tapping on the corresponding option. From the new screen, the teacher can review the complete game history in a table and diagram form. The table presents the student's history, regarding the selected game, in the most detailed form and includes for each session: (i) the date played, (ii) its difficulty level, (iii) the number of helps and mistakes recorded and (iv) the game's score. Students' progress can also be schematically depicted in chart diagrams; one

diagram is provide for the score, one for the mistakes and one for the help requests for each date played (Figure 18 (a)). The teacher can navigate through the dates using the arrows at the bottom of each chart. In addition, through this screen, the teacher can choose to initiate the reviewed game.

Similarly, for each recipe, the system initially presents the basic data and upon selection the detailed ones (Figure 17). Taking into consideration the large number of recipes that will finally be incorporated in the system, the recipes’ menu was designed to be scalable by supporting multiple pages. Moreover, the recipes had to be presented in a compact manner to avoid needless navigation through pages, so they were designed expandable. Tapping on a recipe reveals the recipe’s statistics, which include information on the last time it was selected for each game.

Tapping on the “detailed history” button, the teacher can view further information on the particular recipe (Figure 18 (b)). Score diagrams appear for every recipe-related game (“Let’s cook”, “Find the ingredients”, “Find the utensils”) along with a comparing diagram between the performance in all games. The teacher can navigate through the dates using the arrows at the bottom of each chart or initiate one of these games with the chosen recipe.

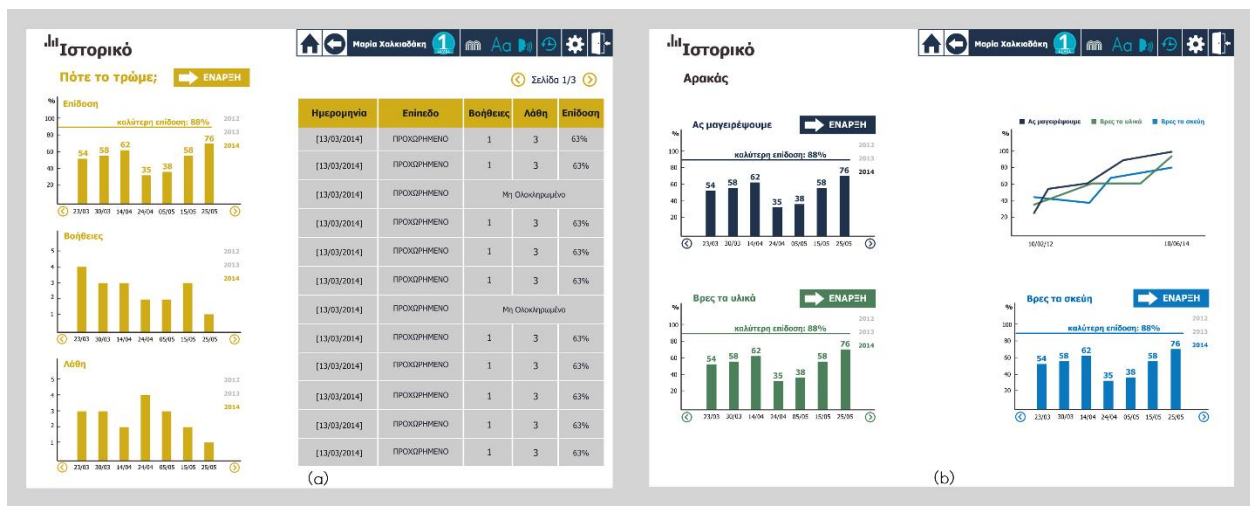


Figure 18. The detailed history data categorized by (a) per game and (b) per recipe.

4.3.4 FINAL VERSION

The evaluation of the full design of CocinAR took place at FORTH's³ premises, where a simulation of the final system's setup was built. The prototypes were projected on a table's surface by a high-resolution projector resulting in an appearance very close to the final system. The complete design was presented step by step, projecting serially the exported prototype images, each of which was evaluated by the Rehabilitation Center's educators, whose comments and observations were recorded through handwritten notes. A final version of the system design was re-designed according to the evaluation results. In general, the evaluation pointed out minor changes in the layout of particular pages, as well as the removal and addition of specific functionality features.

4.3.4.1 The Home Screen

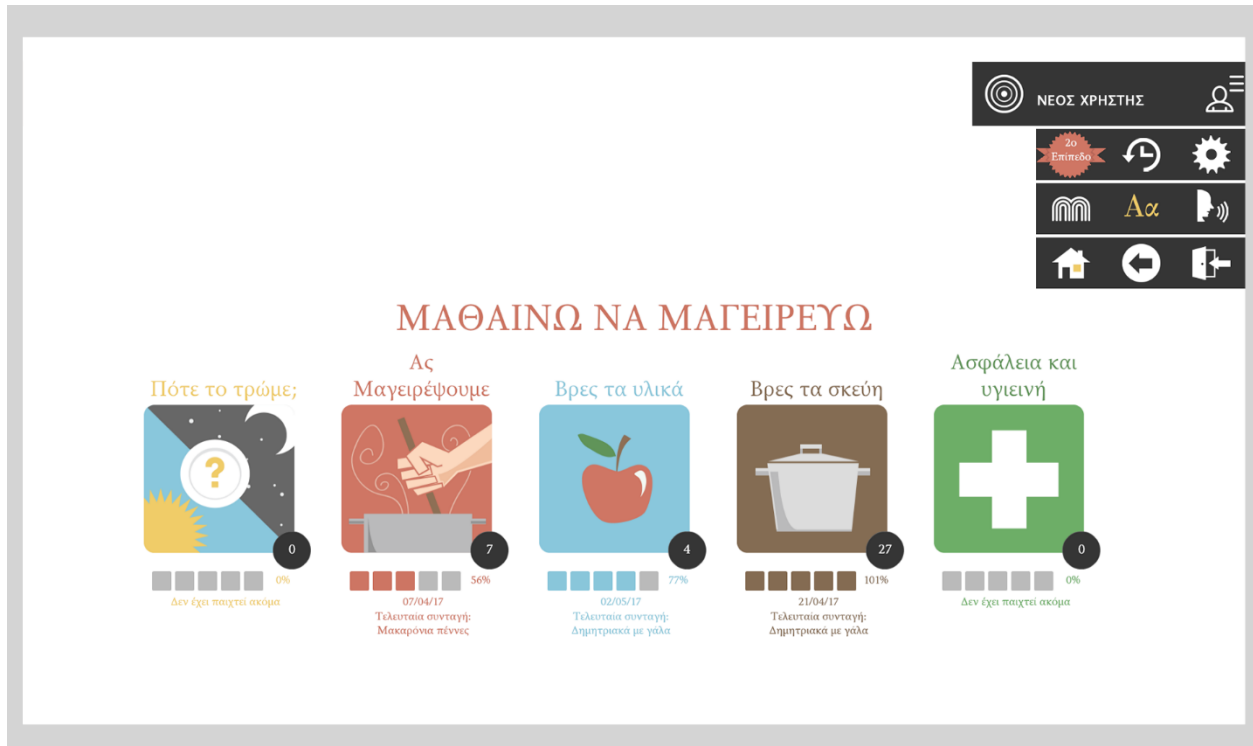


Figure 19. The final version of the system's home screen, with a sliding menu and enhanced statistics representation.

To begin with, all graphic elements were redesigned by a professional graphics designer, enhancing the system's look and feel. Figure 19 depicts the final home screen of the CocinAR system. The updated game's icons adopt a simple, flat design, making them appropriate for children with visual impairments.

³ [Foundation for Research and Technology](http://www.ics.forth.gr) – Hellas, <http://www.ics.forth.gr>

The statistic information presentation was also changed, now showing the number of times a game has been played while the score is displayed in a progress bar.

In addition, the teacher's menu was redesigned to slide open, showing the options separated in categories (Figure 19). In the first row lay the controls related to the user profile, which are the student's level, statistics and preferred settings. The second row contains the content representation options and the last the navigation controls "home", "back" and "logout". The profile information can be edited by tapping on the user name, which appears on top of the options. The teacher can view all the registered students in alphabetical order and choose one for login by tapping on the icon next to the user name.

4.3.4.2 The Recipes Menu

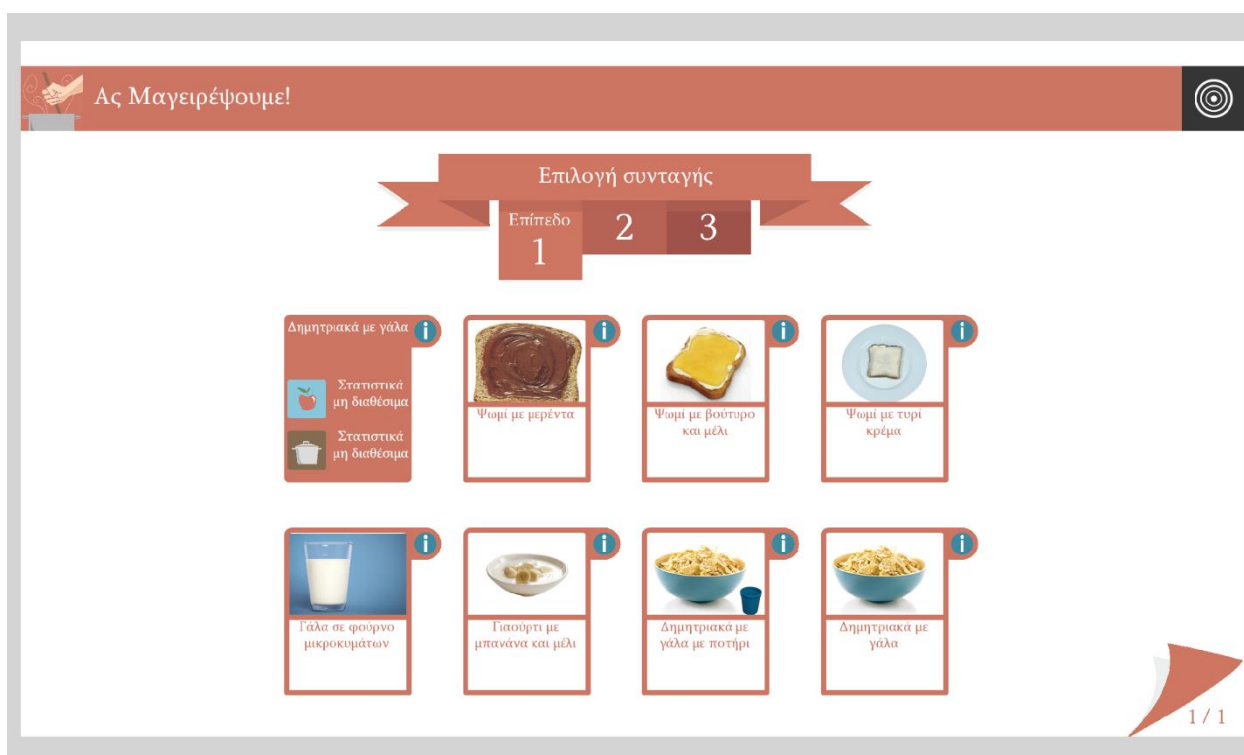


Figure 20. The final recipes' menu compared to the previous design. The recipes are categorized under three difficulty levels and the extra teacher-directed information appears via flipping each recipe.

Furthermore, an important upgrade of the recipe's menu screen (Figure 10) is depicted in Figure 20, according to which the various recipes are now categorized under three levels, easy, medium and hard, facilitating teachers in the recipe selection process. The recipes and their categorization were provided by the RC's teachers and correspond to the same recipes that they teach in the actual kitchen. In addition, the presentation of the teacher-oriented, statistic information was drastically changed. In more details, in

order to facilitate the recipe selection process, a summary of the statistical information became immediately accessible through the recipe selection screen, via a flip functionality for each recipe. Therefore, for each recipe, an “information” icon and the date and score of the last session played became visible with the use of the teacher’s card. By tapping on the “information” icon, the teacher can review the last time this recipe was played by the other two recipe-centered games. That way, the interface becomes significantly less cluttered while increasing the amount of available information for the teacher. Finally, the evaluation indicated that the timer featured was not necessary, but rather frustrating for the children, so it was removed from the final design.

4.3.4.3 The Multiple-choice Games



Figure 21. The final multiple-choice games’ layout. The answer feedback slides up from the bottom of the table and the teacher options “skip” and “force correct” appear via the teacher card.

Regarding multiple-choice games, the design was kept quite similar to the original. Nevertheless, one important adjustment was related to feedback presentation; in the original design, the feedback’s text replaced the text in the question’s frame. According to the evaluation results, this would be confusing for the children, so the feedback was redesigned to appear in a separate position, close to the student (Figure 21). In the new design, a frame appears at the bottom of the table, colored according to the answer’s outcome, containing the appropriate text or symbol language, which is read by the text-to-speech service.

Another minor change is the position of the teacher’s game-flow options, which are now moved closer to the teacher and away from the child’s reach. A “skip” teacher option is provided in the “When do we eat it?” and “Safety and hygiene rules”, which enables the teacher to by-pass a question not relevant to the current teaching goal.

4.3.4.4 The “Let’s cook” Game



Figure 22. The interactive areas of the virtual kitchen, called slots, are marked with a yellow outline indicating that they are selected

CocinAR is designed as a complementary educational system for students with cognitive impairments who also participate in the “Independent living” program of the Rehabilitation Center, where they learn and practice activities of daily living. Consequently, these students have previous cooking experience in the school’s kitchen, so it was a challenge to incorporate the virtual kitchen as an actual part of the physical kitchen. To this end, the virtual kitchen’s interface was redesigned by a graphics designer to resemble the Rehabilitation Center’s kitchen environment with respect to colors and appliances’ positioning (Figure 22).

The virtual kitchen, as shown in Figure 22, illustrates the points of interest (highlighted), which are deliberately confined at the bottom half of the table, so that they are easily reachable by seated or small children. These interactive areas, called slots, may or may not be occupied by ingredients, tools, etc. Four different representation modes (Figure 23) are available for each slot and are interchanged depending on the current situation:

- **The default mode** is the plain slot representation, depicting the element in its original form
- **The selected mode** is the default representation surrounded by a yellow stroke, indicating that the slot is selected
- **The help mode** is the default representation highlighted using the same yellow color, visible when the student asks for help.
- **The activated mode** is applicable in specific slots and indicates that the kitchen appliance is turned on.

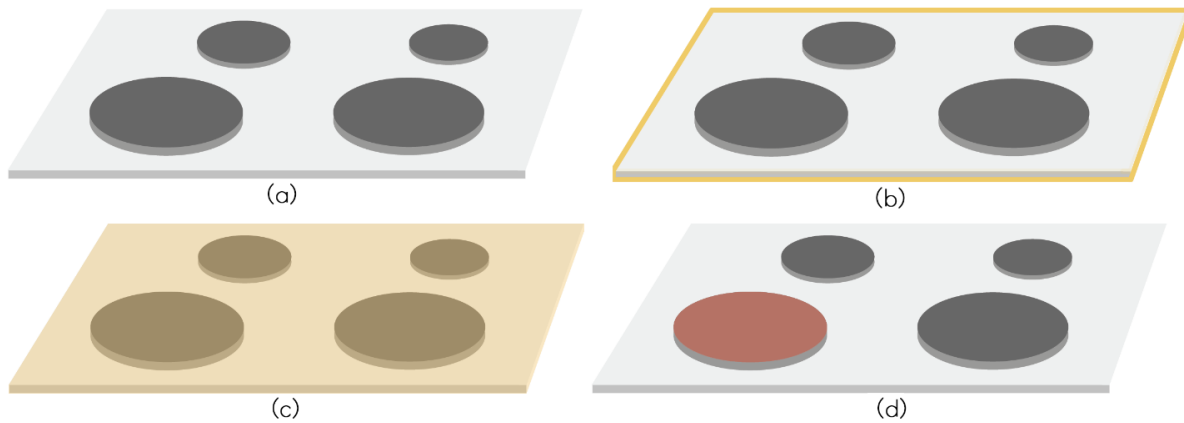


Figure 23. An example of the four different representation modes of a slot. (a) default mode, (b) selected mode, (c) help mode, (d) activated mode

Two specific types of steps require additional graphics components, providing different interaction mechanisms. More specifically, in case of repetitive instructions, an item selection sequence must be repeated for a given number of repetitions (e.g., in the “Put three cups of water in the pot” the student is expected to select the “cup – faucet – pot” sequence three times). Aiming to facilitate the better comprehension of this interaction style, a “Counter” component, shown Figure 24 (a), is designed to increment with each correct repetition. In addition, some steps require a kitchen appliance to be set to a specific value (e.g., “Set the timer to 8”). These steps are performed via a round button, which appears in the middle of the table as depicted in Figure 24 (b), by clicking on the preferred value.

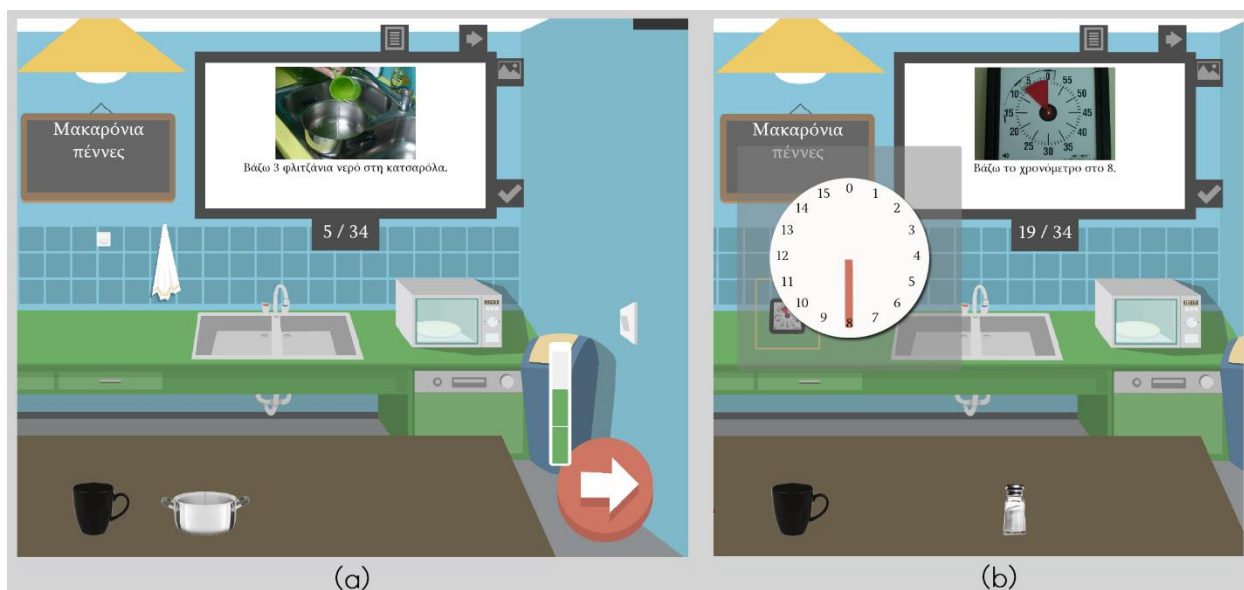


Figure 24. (a) A multiple step with currently two repetitions completed. (b) The set value pop-up, created after selecting the timer

The overall interaction style remained unchanged, with some minor design adaptations, suggested by the Rehabilitation Center's experts. As mentioned in Section 4.3.3.5, after a step's correct answer a video of the actual step process is played. In the initial design, the video is displayed in the recipe step's position, however the evaluators, based on their experience suggested a separate video display to avoid confusion. In the new version (Figure 25), the video is presented as a pop-up in front of the student, drawing his/her attention. The teacher can pause or replay the video by tapping on the display and once the video is closed, the recipe continues to the next step. Another minor upgrade of the previous design is the insertion of an additional teacher control, used to hide the recipe step's image. This feature was requested by the teachers, so they would be able to check if some high-functional students would be able to complete the instruction without the help of an image.

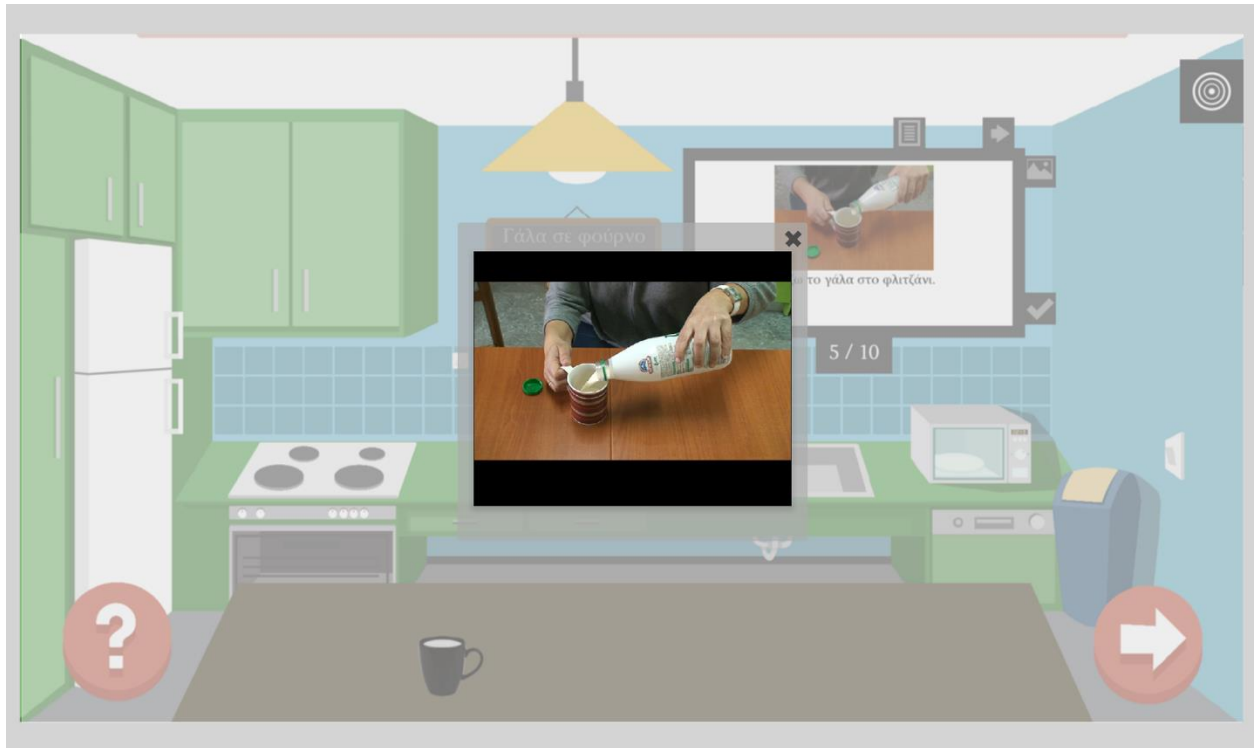


Figure 25. The video is displayed in the middle of the table, fading out the rest of the display.

4.3.4.5 History & Statistics

The History and Statistics pages remained quite similar to the previous design, apart from minor adaptations in the main page, shown in Figure 26. One adjustment required was the altering of the navigation through recipes style, which is now accomplished via move up and down arrows. Another improvement in the design was the removal of the “expand / collapse” arrow button from each recipe option (Figure 17), allowing the teacher to expand the recipe by clicking on its name container instead. The layout of the remaining two user history pages was preserved, adapting the respected game colors.

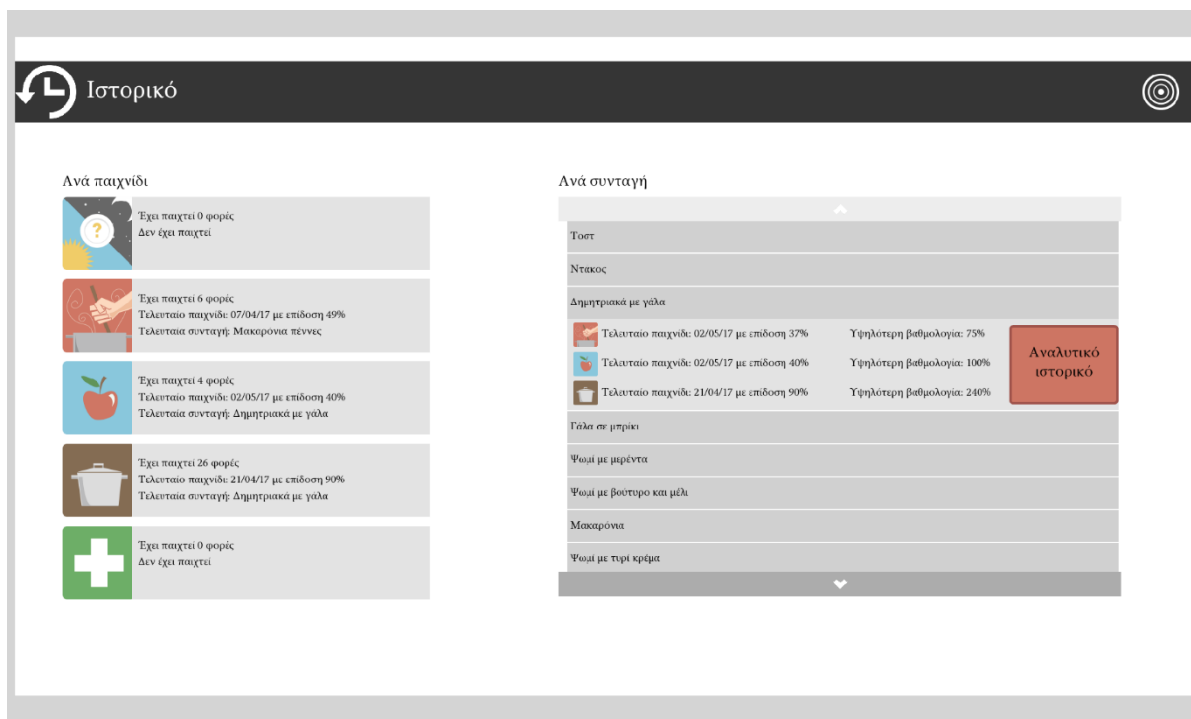


Figure 26. The History Page of the CocinAR application

5 IMPLEMENTATION

The implementation of the CocinAR system was divided into two distinct phases, in order to allow the RC's educators to be involved sooner in the process and provide early feedback. First, a prototype implementation was developed, based on the detailed mockups produced during the design process, featuring part of the required functionality and more specifically the four multiple choice games configurable by the customization menus. In the meanwhile, the system's physical set up was deployed in the RC's kitchen and the computer vision cameras were calibrated. The prototype implementation was installed and evaluated by students of the RC and their teachers, with the aim to assess the produced design as well as the interaction modalities and the system setup. Based on the results of this evaluation, the full CocinAR system version was implemented, adding the "Let's cook" game and profiling functionality. The final system was installed at the Center for pilot use and further evaluation.

5.1 SYSTEM CHARACTERISTICS

The CocinAR system was designed to teach children with cognitive impairments how to prepare basic meals, but it was implemented to be more than that. One of the most important aspects of CocinAR is that it supports configurable interface and dynamic content retrieval, making its functionality completely context free and reusable. In more details, all word phrases and multimedia paths are kept in external files, the styling elements are defined in stylesheets and the various color codes are specified through global constants. The graphic elements' images can also be replaced easily, making the graphics interface completely customizable. As it will be described in the next sections, all recipe related content is dynamically retrieved and manipulated accordingly. This provided configurability allows CocinAR to be repurposed for exercises with different content, preserving its functionality and interaction methods.

Moving on to the implementation details, CocinAR is written using the Adobe Flash Builder 4.7 Premium Platform⁴, which is a development environment for building games and applications using the ActionScript3 (AS3) programming language and the open-source Flex framework. Various technologies were adopted and numerous components were developed in order to create a thorough and structured application. The complete system architecture is depicted in Figure 27 and described in the next sections.

⁴ Adobe Flash Builder 4.7, http://www.adobe.com/gr_en/products/flash-builder.html

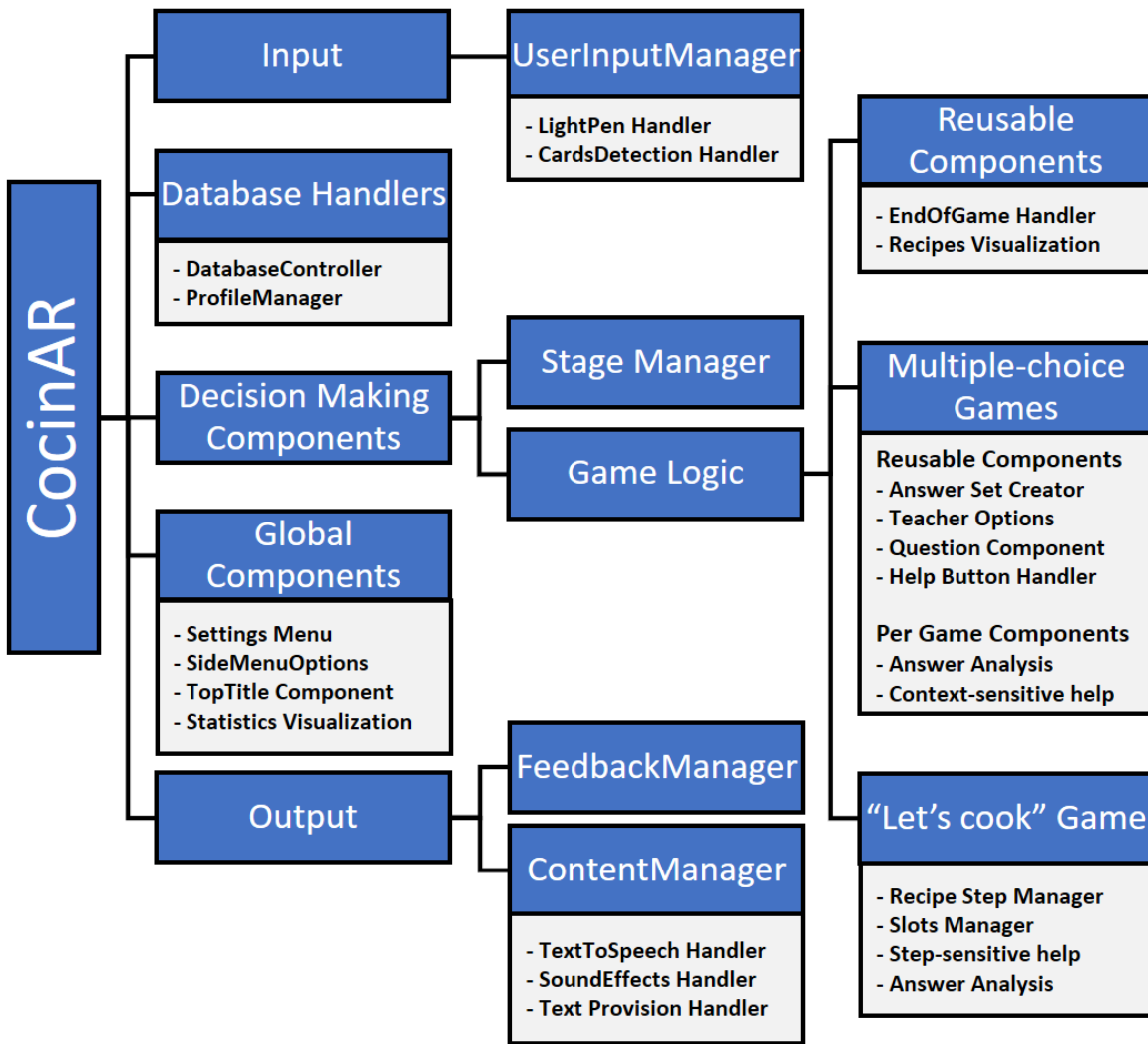


Figure 27. System Architecture

5.2 INPUT AND OUTPUT

CocinAR is a multimodal, adaptable system, which is designed to support comfortable and intuitive interaction. To that end, CocinAR communicates with various external services, some serving as system input mediums, while others facilitate system output.

To achieve the desired augmented reality interaction, two specific computer vision services, developed in the context of FORTH's AMI program were utilized, one for card recognition [99] and the other for infrared light localization [79]. Regarding the interaction through cards, the system's InputManager accepts an event from the card detector service for each card recognized, accompanied by the card's identifier and its coordinates on the table and it forwards it to the appropriate components. Moreover, the InputManager generates an additional event, dispatched when the teacher card appears on the table, activating or deactivating the teacher-oriented content.

The second user input method is through an infrared pointing device, in our case the stamp or an infrared stylus. In general, a pointing device equipped with an infrared beacon, when slightly pressed against the table's surface, generates an invisible to the human eye light, and thus is detected by the infrared light detection camera. Once that happens, the InputManager receives the device's location on the table from the LightPen service and dispatches a "click-equivalent" event with the corresponding coordinates to the interested pages. Each page then, checks if the returned coordinates activate any of its interactive elements, which handle the event accordingly.

Regarding system output, CocinAR is designed to support not only visual, but also audio output, aiming to facilitate interaction for children with possible visual impairments and children with cognitive disabilities who cannot read. To that end, a text-to-speech service is utilized, which is responsible for the auditory output of the system. Depending on the context, CocinAR promotes the desired phrase to the text-to-speech service, which is vocalized by a female voice, while an event indicates the end of the speech. Service settings include whether or not the voice is activated and the volume and speed rate, all configurable through the Side Menu Component described in section 5.5.2.

The communication of CocinAR with the aforementioned services is supported by a middleware layer based on CORBA, developed for the intercommunication of applications and services [134]. The middleware layer offers tools and libraries that allow the creation of services using Application Programming Interfaces (APIs) in any of the supported programming languages, C++, .NET languages, ActionScript and Java. The services running using the middleware can be spread across the network and programmers do not interfere with network connection establishment. On the contrary, developers focus only on the functionality that each service should offer, implementing the desired interfaces as a service and creating wrapper classes that can handle incoming data for any client that receives them.

As explained in the previous chapters, multimodal output is a fundamental service of the CocinAR application, providing adaptation to the various characteristics and preferences of children with cognitive impairments. The component controlling the form of the system's output is the ContentManager, which handles all content representation related components and defines their characteristics. In other words, content provision settings such as audio volume and speed rate, font size, sound effects activation, etc., are stored into and manipulated via the ContentManager.

The system's response to a user's answer, or in other words the feedback, is treated as a special kind of output, also available multimodally. The component handling the presentation of the feedback is the FeedbackManager, which is triggered after each correct or wrong answer. The FeedbackManager's role is to display the appropriate visual feedback using coherent and simple animations and to reproduce the respected audio response and sound effects.

5.3 DATABASE MANAGEMENT

All data manipulated and presented by the CocinAR application are stored in external databases and retrieved on demand. Two distinct databases exist, the Content database, which contains all recipe-related information (e.g., the ingredients and their characteristics, each food's recipe steps, etc.), and the Statistics database, which keeps a profile and the interaction history for each student. In the next sections, the management of these databases is analyzed.

5.3.1 CONTENT DATABASE

CocinAR gains content independence by deriving all recipe-related content from the Content database. The database's content is accessed via data retrieval functions, accessible through a middleware layer. A wrapping library is responsible for reconstructing the database's schema into AS3 classes and providing an appropriate API for their manipulation. Afterwards, these classes are initialized and used by the DatabaseController, which facilitates the communication between the Content database and the CocinAR application. A representative subset of the supported retrieval functions is depicted in CodeBlock 1.

```
/* ----- BY ID ----- */  
  
public function getInteractiveObjectByID(entityID:Number) :InteractiveObject{[]  
  
public function getFoodByID(entityID:Number) :Food{[]  
  
public function getIngredientByID(entityID:Number) :Ingredient{[]  
  
public function getPotteryByID(entityID:Number) :InteractiveObject{[]  
  
public function getKitchenApplianceByID(entityID:Number) :KitchenAppliance{[]  
  
public function getMinFoodByID(entityID:Number) :Food{[]  
  
/* ----- BY FOOD ----- */  
  
public function getIngredientsOfFood(fd:Food) :Array{[]  
  
public function getPotteryOfFood(fd:Food) :Array{[]  
  
public function getIngredientsNotOfFood(fd:Food) :Array{[]  
  
public function getPotteryNotOfFood(fd:Food) :Array{[]
```

CodeBlock 1. A representative subset of the retrieval functions provided by the DatabaseController

5.3.2 STATISTICS DATABASE

A back-end mechanism was developed for the storage and manipulation of all user profiles and interaction history data (Figure 28).

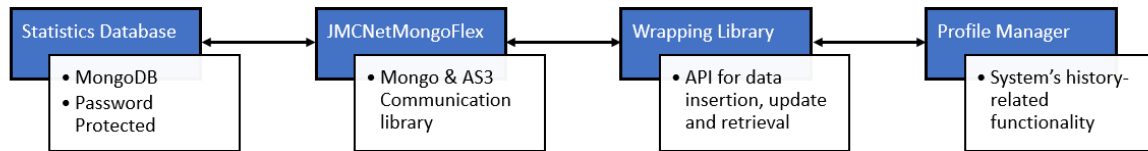


Figure 28. The communication flow between CocinAR and the Statistics Database

Considering that the user's profile data is sensitive information, it had to be stored in a secure database, accessible only by the RC's educators. To accomplish that, a non-relational MongoDB Database is utilized, which is accessible only via the CocinAR system, using a private username and password. JMCNetMongoFlex is an AS3 library, which provides direct functions for inserting, updating and retrieving data from a MongoDB Database and is employed by the system's ProfileManager. A special wrapping library maps the raw profile data into AS3 classes and provides a retrieval and insertion API used by the ProfileManager in order to communicate with the database.

The Profile Manager is responsible for all profile related functionality such as registration, profile editing, history recording, etc. When a user signs in the system, it first authorizes the profile's information retrieval and then notifies the ContentManager to apply the user's last used settings to the system, thus personalizing the interaction. Moreover, the Profile Manager stores a detailed description of the user interaction for each game session and stores it in the database at the end of each game session.

5.4 THE STAGE MANAGER

The Stage Manager is one of CocinAR's decision-making components, which orchestrates the exchange between the various pages of the system, namely games, menus, or settings. It is implemented to operate as a stack, having each new page displayed on top of the previous. When the "back" button is clicked, the top page is removed to reveal the underlying one, following the last-in-first-out protocol.

This approach arose an unexpected challenge, which had to be overcome for the system's smooth functioning. As already mentioned, the user can interact with CocinAR via an infrared pointing device, which upon touching the table's surface dispatches a click equivalent event on the corresponding coordinates. Each page, then, checks if the returned coordinates are included inside any interactive element, which handles the event accordingly. The interesting part was that all underlying pages were also receiving the event even if they were overlaid, so the StageManager was expanded to deactivate the input events in the hidden pages.

5.5 GLOBAL UI COMPONENTS

The components described in the following sections constitute application features that are accessible in every part of the user's interaction. These elements serve in a variety of ways, each fulfilling a different purpose.

5.5.1 TOP TITLE COMPONENT

The TopTitle component simply serves as the system's "header", adapting the title, color and, if applicable, the image to the current page. Exceptions constitute the home and "Let's cook" game pages, where a header is unnecessary and thus, hidden. The title's adaptation to the current screen is handled by the StageManager (Section 5.4), which is responsible for the exchange between pages.

5.5.2 SIDE MENU

The SideMenu component, depicted in Figure 29 is the teacher’s most practical tool and is used throughout the system session. Firstly, it provides navigation functionality, allowing the user to either return to the previous page or to the home page instantly. When the navigation controls are clicked, the SideMenu component sends an event to the StageManager in order to handle the navigation process. The StageManager also receives an “exitApplication” event dispatched by the SideMenu when the exit icon is clicked, and acts accordingly.

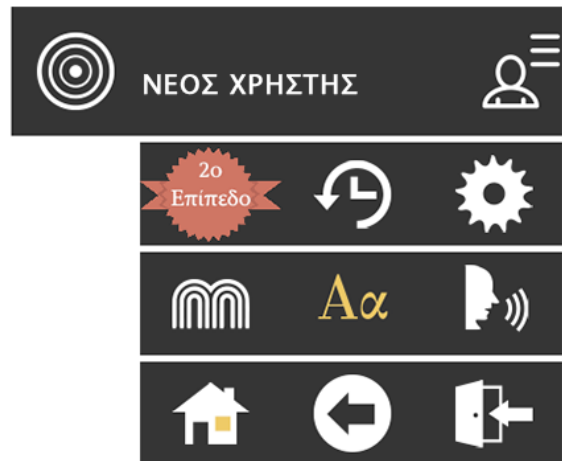


Figure 29. The SideMenu component.

Another set of controls included in SideMenu are the content visualization options. This part communicates with the ContentManager, which stores the current content representation preferences and distributes them to the rest of the pages. Student’s changes of game level are also handled by the ContentManager, since the fundamental difference between the two levels is the content’s visualization complexity.

Initially, the settings applied in the SideMenu component are the default; however, when a user signs in, they are automatically updated by the ProfileManager.

5.5.3 SETTINGS MENU



```
<elements:stateButtonComp id="sizeButton" buttonLbl="Μέγεθος γραμματοσειράς: " st1Id="lsz1" st1Lbl="Μικρό"  
  st2Id="lsz2" st2Lbl="Μεσαίο" st3Id="lsz3" st3Lbl="Μεγάλο"  
  selectedState="{contentMgr.text_size}" numOfStates="3"/>  
  
<elements:stateButtonComp id="textButton" buttonLbl="Παρουσίαση κειμένων: " st1Id="txt1" st1Lbl="Απλή"  
  st2Id="txt2" st2Lbl="Κανονική"  
  numOfStates="2" selectedState="{contentMgr.simple_text}"/>
```

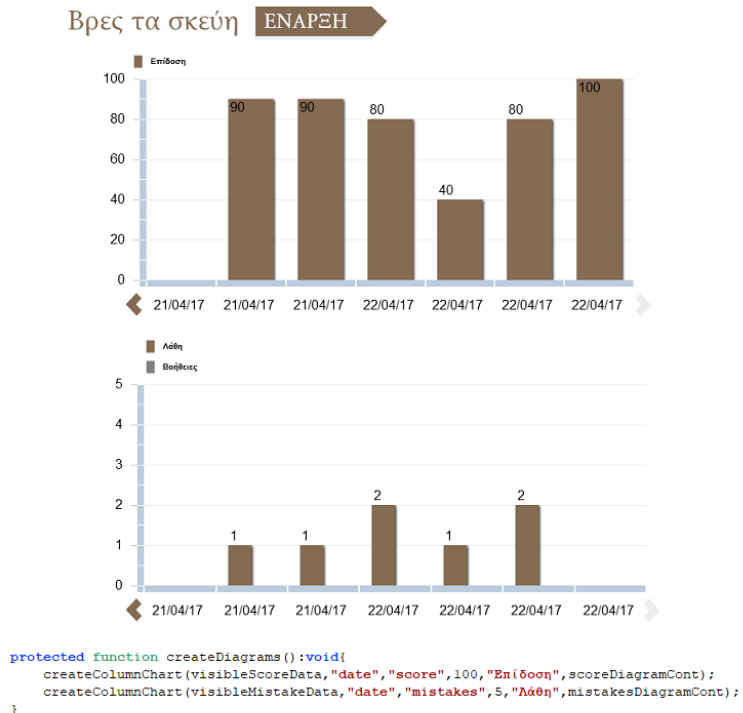
CodeBlock 2. The custom element StateButtonComponent

Additional customization settings can be applied from the SettingsMenu page. The custom StateButtonComponent (CodeBlock 2) was developed to support a customizable number of options per button (in our case two or three). The updated settings are delivered to the ContentManager after the user leaves the SettingsMenu page.

5.5.4 STATISTICS VISUALIZATION

Any time during the interaction, the teacher can choose to review the student's interaction history and statistics through the SideMenu Component. The statistic information is displayed in two different forms, as described in Section 4.3.3.6, per game and per recipe.

Each of the five different game options is represented by one customizable component, the GameStatsOption, which displays user history information derived from the Statistics database via the ProfileManager. Each option, once clicked, notifies the StageManager to create a new page, which displays detailed information about all the sessions played in the particular game. The complete interaction history is visualized via the AdvancedDataGrid and ColumnChart Flex components used for creating tables and column charts respectively (CodeBlock 3).



CodeBlock 3. The charts' creation

The "Per recipe" menu is implemented similarly, displaying a list of custom-made, expandable buttons, the RecipeStatsOption components, which once clicked, provide detailed information about all the games played with the selected recipe. The complete interaction history is visualized via the LineChart and ColumnChart Flex components used for creating line and column charts respectively.

5.6 GAME LOGIC

Although CocinAR includes five different games, their development involved many reusable templates, leading to a fast and structured implementation. All common functionality of the various pages is implemented once and is modified by each page accordingly. The reusable components are initialized in each game separately, and instantiated with the appropriate content. In the following sections, the characteristics of the reusable and context-specific components are analyzed.

5.6.1 RECIPES VISUALIZATION

The intermediate step before the beginning of a game is to select one of the available recipes. The recipes provided by the RC's experts may be of any number and difficulty, so their visualization had to be expandable and categorized under three levels. These requirements were implemented into one reusable component, the RecipesMenuComponent, which creates a RecipeMenuOption element for each available recipe and categorizes them according to their difficulty level. The RecipesMenuComponent is configured depending on the selected game to display different recipes, using the corresponding color of the game and the appropriate statistics information, as shown in Figure 30.

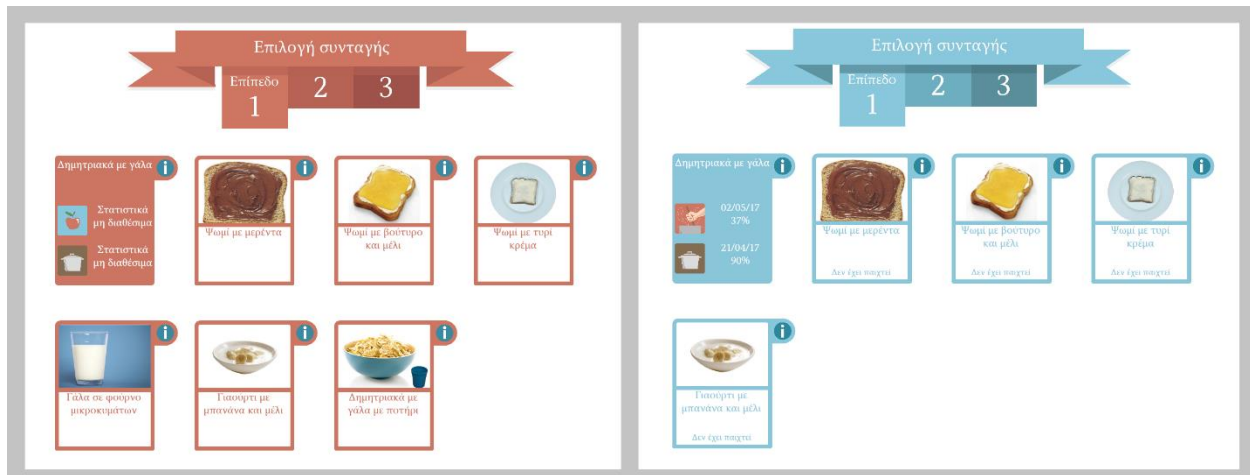


Figure 30. The RecipesMenuComponent configured for the two different games. The “Let’s cook” game on the left and the Find the ingredients game on the right.

5.6.2 END OF GAME HANDLING

A game is finished when all the required steps of the recipe are executed or all the questions are answered. In that case, an EndOfGameComponent is created, which apart from providing auditory and visual congratulation to the student for completing the game, also notifies the ProfileManager to update the statistics database with the acquired interaction information.

5.6.3 MULTIPLE-CHOICE GAMES

The four multiple-choice games follow a common design model, thus allowing many of the necessary components to be developed as reusable elements. These elements are:

1. **Teacher game-flow options.** These are the small buttons, which slide their way in from the sides of the table when the teacher card appears. They offer the same functionality in all of the multiple-choice games that is, either to “skip” a question or consider an answer correct regardless of the actual outcome. The TeacherOptionsComponent element is responsible for executing these functions, as well as to adapt its appearance according to the played game.
2. **Answer Set Creator.** The AnswerSetCreator class is responsible for generating the multiple-choice options to be presented to the student. This set of options consists of one to three correct answers, randomly spread along the questions, mixed with random wrong options. It is created as in CodeBlock 4.
3. **Question Component.** This component handles the visualization of the question of each game, with respect to content and appearance. It also provides a “replay” functionality, which allows the child to listen to the question on demand, just by tapping on the element.
4. **Help Button Handler.** Another common functionality of the multiple choice games is the type of help provided to the student. In more details, when help is requested, one of the wrong options starts to fade out using a fading animation, until it completely disappears. When it is called a given number of times, the help handler leaves only the correct options visible.

```
/** Creates and returns an array of multiple choice options sets */
private function getRandomAnswersSet():Array{
    var randomAnswerSet:Array = new Array();
    numOfQuestions = getNumberOfQuestions();           // depending on the # of correct answers
    allCorrectAnswers=randomizeArray(allCorrectAnswers);
    randomAnswerSet = splitCorrectAnswers(allCorrectAnswers); // assign 1-3 correct answers in each set
    randomAnswerSet = fillWithWrongAnswers(randomAnswerSet); // add wrong answers to each set to end up
                                                            // with 5 options and randomize them
    return randomAnswerSet;
}
```

CodeBlock 4. The AnswerSet Creation

The context-dependable element which differentiates each multiple-choice game, is the composition of the system's response to the accepted answers. Each received answer is analyzed with respect to the specific context, that is what answer is given for a particular question, and then the appropriate feedback is constructed and dispatched to the FeedbackManager. Moreover, during the answer analysis, the ProfileManager collects information on the user's selections, mistakes, help requests, etc.

The nature of interaction changes completely in the second level, where the user has to find the correct answers among all available cards. In this case, no answer set is created; the system instead utilizes the card detection service to recognize the cards placed inside a designated area on the table. The cards are not checked for correctness until the answer is confirmed via the next button, when they are analyzed to deliver the resulting feedback to the FeedbackManager.

5.6.4 "LET'S COOK" GAME

The "Let's cook" game constitutes the main and fundamental educational game of the CocinAR system and its implementation is completely different from the rest of the games. As described in the previous chapters, the purpose of this game is to guide the user through the steps of a recipe in order to prepare a meal. All recipe characteristics (name, picture, level, etc.) are retrieved from the Content database along with information on each step's interaction type and the actions needed in order to be executed correctly.

The summarized lifecycle of a recipe step begins with the retrieval of this information and continues with the initialization of the respected elements. The RecipeStepManager undertakes to prepare the game's interface according to the current step's type and the user interaction is ready to begin. Next, the SlotsManager records all clicking actions, keeping track of the slots selected at any given moment. When the student is ready and confirms the answer, the slots selected are compared to the expected ones by the RecipeStepHandler and the appropriate feedback is dispatched to the FeedbackManager. After the feedback provision and provided that the step is correctly executed, the step's video is reproduced and, when closed, the used virtual elements are refreshed and the recipe proceeds automatically to the next step. In the next sections, the components implemented to provide this functionality are presented.

5.6.4.1 Recipe Step Handler

The RecipeStep constitutes a structural element used in the CocinAR's meal preparation process. It contains the step's representation information such as description, image and video, but more importantly, it includes the sequence of actions a user must follow for its execution. Each step is categorized by its interaction type, which may be: a card's retrieval, to move an element to another slot, the combination of elements, to set a specific value to an appliance, to plug or unplug a device, to turn a device on and off and to wait for a process to end (Table 2). For each of these types, the RecipeStep keeps

a list of the involved elements, their starting and resulting positions and other information relevant to the execution.

Table 2. The RecipeStepHandler's actions for each step type

Step Type	Initialization	Preparation	Amendment	Result
Card	Retrieve the expected card ids	Show cards' placeholder	Compare selected card ids with the retrieved ones	The respected virtual items appear on the table
Move	Retrieve the expected slot ids (startSlot, endSlot)	-	Compare selected slot ids with the retrieved ones	The startSlot's item is moved into the endSlot
Combine	Retrieve the expected slot ids and the resulting combined items' data	-	Compare selected slot ids with the retrieved ones	The resulting combined items appear and any unnecessary items are removed
Multiple Combine	Retrieve the expected slot ids, the number of repetitions and the data of the resulting items	Show counter bar	In each repetition, compare selected slot ids with the retrieved ones	The counter is incremented with each repetition. When it is full, the Combination result is performed
Plug	Retrieve the id of the appliance to be plugged or unplugged	-	Compare the selected appliance with the retrieved one and check that one of the plugs is selected	The appliance appears plugged or unplugged
Activate	Retrieve the id of the appliance to be activated or deactivated	-	Compare the selected appliance with the retrieved one	The appliance appears activated or deactivated
Set Status	Retrieve the id of the appliance and the value to be set	Show set value switch	Compare the selected appliance and the value selected with the retrieved one	The appliance appears activated or deactivated
Wait start/stop	-	Show timer animation	-	Automatically move on to the next step

The step's initialization, the amendment of students' actions for each step and the transition between the recipe steps are handled by the RecipeStepHandler element. Each step is initialized according to its interaction type; for instance, a "card retrieval" step will initiate a slide-in animation to the CardsPlaceHolder element, which will activate the card detection service. Analogous actions are taken for the initialization of the remaining recipe step types, if necessary.

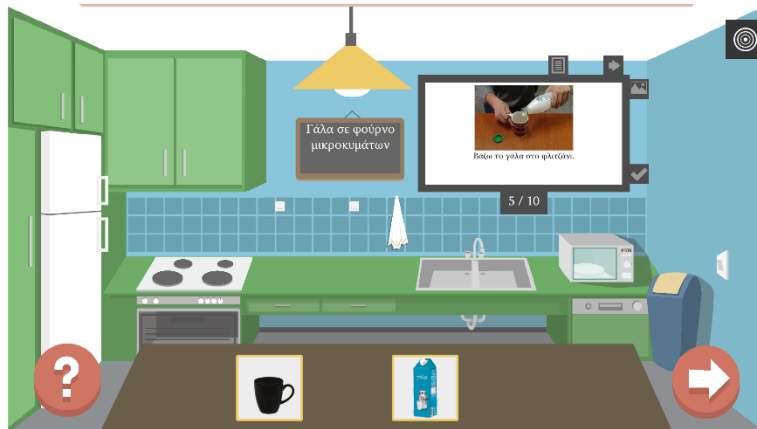
RecipeStepHandler is also responsible for the amendment of the answers given for each step. Again, the step's type defines the way the step will be handled through the evaluation process. For example, a RecipeStep of type "move", provides the starting position (slot) of an element along with the slot it should end up when the step is completed, which when compared to the user's clicked slots can produce the answer's result.

The result generated by the answer's analysis is communicated to the FeedbackManager and depending on its correctness, the respected items will be updated and the transition to the next step will be scheduled or not. In case of wrong answer, a piece of advice is presented by the FeedbackManager and the student is encouraged to retry the same step. A positive outcome of the analysis alerts the FeedbackManager to reproduce the video, whose ending indicates that the next step is ready to be initialized.

5.6.4.2 Slots Management

Another significant element of the “Let’s cook” game are the designated interactive areas of the virtual kitchen, called Slots. Slots may be kitchen appliances, positions on the virtual table or on the virtual kitchen counter, plugs, the sink, etc. All the available slots are depicted in Figure 22. For each slot object used in the CocinAR application, an equivalent one is maintained inside the Content database. That way, there is a correspondence between the interactive interface of the game and the information kept in the database. Moreover, each slot may or may not contain an interactive element in it, for instance, a pot may be on the kitchen stoves, or a plate may lay on the table.

Four different representation modes are available for each slot (see section 4.3.4.4), which are set by the SlotsHandler depending on the current situation. During the step’s initialization, all slots are switched to the default mode, whereas tapping on a slot activates or deactivates the selected mode. Moreover, when a slot represents an activated kitchen appliance, it is depicted in the activated mode, while tapping on the help button activates the help mode.



(a)



(b)

Furthermore, tapping on a slot notifies the SlotsHandler to update accordingly a list of clicked slots and their containing items, if any. When an answer is ready for evaluation, the list of clicked slots is compared to the list of clicks expected and if they are equivalent, the SlotsHandler updates the slots' contents accordingly. For instance, in Figure 31 (a), the “cup” and “milk” elements lay inside the second and forth slot of the table. For the correct execution of the “Put milk in the cup” step, the user clicks on these slots, selecting the contained items. When the “next” arrow is pressed, these two clicks are checked for correctness and the slots' contents are refreshed. In Figure 31 (b), the “milk” and the “cup” item are removed and the combined item “cup with milk” takes their place.

Figure 31. (a) The step “Put milk in the cup”. The cup and milk items are selected. (b) The resulting object of the previous step.

5.6.4.3 The Step Execution Protocol

A communication protocol between CocinAR and the Content Database's was adopted in order to provide a structured definition of each step's execution. In other words, CocinAR receives from the database all the data of the interactive elements that are necessary for a step's execution in a strictly defined format and handles the initialization and analysis of each step in an automated way. More specifically, for any given step as shown in Table 2, the database knows exactly which slots should be selected, or which cards should be chosen and also keeps each interactive item's position. That way, an answer is checked by comparing the lists of the expected versus the actual items clicked by the user. Basically, the “Let's cook” game applies standardized rules for the process of each step type, regardless of the actual content of the step, and thus supports content independence.

5.6.4.4 Teacher options

The game flow options provided in this game include a “next step” and “force correct” functionality for each step, handled by the RecipeStepHandler accordingly. In the first case, the recipe moves on to the next step without any feedback or video displayed, while in the second, the system congratulates the student as it normally would.

The “Show picture” option’s functionality is to simply show or hide the step’s explanatory photo, while the “Recipe progress” option creates a “StepsListPopup” popup window displaying all the steps in compact form. The compact recipe steps are implemented as a custom element, which can be expanded to view the step’s explanatory photo.

5.6.4.5 Step-sensitive help

The help provided by the system in this game depends on the particular step in which it was requested. For instance, in a “Combine” step, the slots to be selected will be turned to the help mode by the SlotsHandler and in a card’s retrieval step, the FeedbackManager will give an advice like “Put the cup card on the table”.

6 EVALUATION

The evaluation of the CocinAR system was conducted in two distinct phases, a formative and a summative one, both conducted at the Rehabilitation Centre's kitchen area, where children are taught to prepare simple meals. The formative phase examined the system's prototype implementation, aiming to draw some general conclusions about the system and the user experience, which were used afterwards for the refinement of the final implementation. In the second phase, the fully functional system was evaluated, focusing on the assessment of the "Let's cook" game and the multimodality of the interaction.

6.1 EVALUATION OF THE DEMO PROTOTYPE

The first round of evaluation with real users was conducted on the system's demo prototype, which included both levels of all the multiple-choice games, along with the system personalization settings.

6.1.1 GOAL

The goal of the evaluation was primarily to examine the overall usability of the system both in respect to its physical attributes and its functional features. It would be the first time that the children would interact with the table-top surface using cards and the newly developed pointing device, so the intuitiveness of the interaction methods could also be examined. At the same time, this evaluation also aimed at assessing the overall user experience of the children and their teachers.

6.1.2 PARTICIPANTS

A total of nine children participated in the evaluation, covering a wide range of developmental disabilities and functional capabilities (from level 0-3, with 0 being the least functional and 3 the most functional). Five of the children were boys and four were girls. Two consensus forms were given to the children's parents to sign, indicating their consent regarding their child's participation in the experiment and the use of video recording equipment. In addition, four teachers participated in the experiment, a speech therapist, a special education teacher, and two occupational therapists.

Table 3. Disabilities and level of functionality of the preliminary evaluation's participants

Disability	Children	Functionality Level
Autism Spectrum Disorders	4	0, 1, 1, 2
Down syndrome	2	2, 2
Cerebral palsy	1	2
Psychomotor impairment	2	3, 3

6.1.3 METHODOLOGY

The evaluation method that was used for the experiment was that of user observation. For this purpose, two usability experts were present during each session and were situated at a distance from the child and the teacher to avoid distracting the child. During each session, the experts paid close attention to the way both the child and the teacher interacted with the system, while a video camera, angled in a way that the children's faces were not visible, recorded each session to allow further analysis. The experts did not interrupt or speak during the session, allowing the teacher and the child to use the system freely and as they normally would. Prior to the experiment, the teachers were thoroughly trained on how to use the system and its interaction modes. An observation protocol form (see Appendix I) was used by the observers to comprehensively mark down specific interaction behaviors and user preferences, as well as the performance of the system features. At the end of all the sessions, a quality data report was put together, which presented the conclusions of the experiment.

6.1.4 RESULTS

This phase of the experiment allowed to draw some general conclusions about the system and the user experience in the form of qualitative data. Overall, the system fared well with the children and the teachers. The children's initial reaction to the system was mainly that of excitement and curiosity, but after a while they settled down and were able to focus on the activities presented to them. For the children with lower levels of capabilities (level 0 and 1), the teachers had to guide them continuously on how to interact with the system and help them use the pointer device, but that was expected due to the characteristics of their disability. The more functional children (level 2 and 3) were able to immediately follow what was actually going on with the exercises and could use the pointer device independently. All children were able to distinguish the interaction elements that were displayed on the table.

However, some children seemed to miss a lot of the questions that were given verbally by the system and, as a result, the teachers had to often repeat them. In addition, it was observed that the children with

psychomotor impairments had more trouble to accurately point and hold the pointer device over a selection. The problem was attributed to the fact that the sensors of the device that are situated at the bottom are too sensitive for this kind of usage.

6.1.5 LIMITATIONS

Since this technology was completely new to both sets of users, a lot of questions were raised in concern to whether the children would find it fun or stressful, distracting or engaging, boring or exciting and whether the teachers would find it conducive and supportive to their learning model. These are questions that cannot be answered in just one evaluation session per child. Recognizing this limitation, the decision was made to carry out further evaluation sessions with the same participants over a longer period of time and to draw more concrete conclusions about the system and the technology used.

6.2 EVALUATION OF THE “LET’S COOK” GAME

A second round of evaluation was conducted for the system’s implementation of the “Let’s cook” game, which is the more fundamental and complex game of the system.

6.2.1 GOAL

The goal of the evaluation was primarily to examine the overall usability of the “Let’s cook” game both in respect to its physical attributes and its functional features, while at the same time, to find out whether the particular design tactics used were appropriate for children with intellectual disabilities. The research questions that the evaluation aimed to answer are:

- a) Is the adopted graphic style appropriate for children with cognitive impairments?
- b) Is multi-modal input appropriate for children with cognitive impairments?
- c) Is multimedia output appropriate for children with cognitive impairments?
- d) Does multi-modal interaction in any way inhibit the educational purpose of the system?
- e) Does multi-modal interaction in any way enhance the user experience making it more engaging for children and thus facilitate the educational purpose?

Answers to these questions were obtained by evaluating the overall user experience along with the individual design choices made, with respect to their appropriateness for children with cognitive impairments, namely:

- The graphics used to represent the virtual kitchen
- The use of printed cards as a means of interacting with the system
- Using a specially designed pointing device as a means of interacting with the system
- The sounds used for feedback and instructions
- Playing video as a means of rewarding the learner and as an educational tool for repeating and consolidating educational information
- Using multiple ways of interacting with the system (cards, pointing device).

6.2.2 PARTICIPANTS

In order for the “Let’s cook” game to be reliably examined, its evaluation had to include the system’s target user group, which are children with cognitive impairments and their teachers. Having already a long and successful collaboration with the RC’s educators, it was only natural to involve the RC’s students and teachers in the final system’s evaluation process.

The selection criteria for the participants of the final evaluation were the following:

- a) Students must attend the RC, have acquired a signed consensus of participation by their guardian and have played the game at least once before.
- b) Educators should be teachers at the RC who have integrated the system in their educational activities.

Following these criteria, twelve children and their educator participated in the evaluation (Table 4). The children who were selected to participate covered a wide range of developmental disabilities, while their functionality level varied from 3-5 in a 1-5 scale, with 1 being the least functional and 5 the most functional. Regarding the demographic data of the participants, the user sample consisted of six boys and six girls, aged from 9 to 17 years old. Because of their age, their guardians were requested to sign a consensus form, indicating their consent regarding their child’s participation.

Additionally, CocinAR is a tool to be used regularly during the rehabilitation treatment of the target user group, therefore all participants were scheduled to have played the “Let’s cook” game exactly once before, in order to examine the actual interaction difficulties, avoiding first time encounter errors. The same recipe, the penne pasta, was “cooked” by all children both before and during the evaluation, in order to examine different users in the same context of use. This particular recipe was chosen because most of the children have also learned how to prepare it in the real kitchen, aiming to draw possible valuable conclusions from this fact.

Table 4. Disabilities and level of functionality of the second evaluation's participants

Disability	Children	Functionality Level	Reading skills
Autism Spectrum Disorders	2	4, 5	Yes, Yes
Down syndrome	3	3, 4, 5	Somewhat, Somewhat, Yes
Psychomotor impairment	2	4, 4	Yes, No
Mental Retardation	2	4, 5	No, No
Cerebral palsy	3	3, 4, 4	Somewhat, Somewhat, Yes

Another important characteristic of the participants was the level of their reading skills. According to information provided by their teachers, five of the children were able to read adequately, four had elementary reading skills and could read only short and simple sentences, while three of the children could not read at all.

6.2.2.1 Participation consensus

The guardians of the children that agreed to have their children participate in the evaluation were given a consent form which informed them of the purpose of the evaluation, the process that was going to be followed, the methodology used for the results analysis. They were also informed that it was the performance of the system that was being examined and not that of the children and that the analysis and presentation of the collected data was going to be done in an anonymous way. Finally, they were informed that the participation was voluntary and that they could withdraw their consent at any point before the evaluations. The form included the evaluator's contact information in case of further questions.

6.2.3 METHODOLOGY

The methodology used for the evaluation of the CocinAR system was that of user observation. The observation was done by two usability practitioners experienced in user-based evaluations. All participants were asked to "cook" a recipe through the "Let's cook" game, under their teacher's guidance, while the evaluators would observe the sessions. The evaluators were situated at an appropriate distance from the child and did not interrupt or speak, allowing for the teacher and the child to use the system freely and as they normally would. The RC educator would place the observed child in front of the table and the rest of the participants next to or behind it. The evaluation sessions were spread along a five days' interval, keeping each session's duration the same as in their usual class.

Aiming to a more effective capture of the quantitative and qualitative data observed during the sessions, two specially prepared observation protocol grids were designed. The first observation protocol, the "Step Observation Protocol", was designed to record quantitative data about the interaction during each individual step of the recipe, i.e., how many mistakes were observed, which items or cards were selected incorrectly, etc (see Appendix II). The second observation protocol, the "General Observation Protocol", was designed to record the user's overall interaction experience with the system, i.e., if there were any

interaction problems with the cards or the pointer device, if user expressed any difficulties with any part of the game, etc (see Appendix III).

At the end of each session, the teacher was asked clarifying questions by the evaluator, about specific actions or errors of the current participant. This mini-interview was necessary for resolving possible confusing behaviors of the participants during the session. Finally, the evaluator concluded the session by thanking the educator and the student for their time.

At the end of all the sessions, the educator was called to answer more general questions, concerning the students' overall interaction with the system, their likes and dislikes and the system's value for the teachers. For these questions, the semi-structured interview [32] method was followed, in which one of the observers asks questions to the teacher and records his or her observations and comments. The method of semi-structured interviews includes a set of ready-made questions, while further questions can be made depending on the course of the interview. The second observer did not interfere with the interview, apart from simply helping to collect and record all the above data.

The observation results and the answers collected during the experiment were recorded, kept and analyzed following an anonymity protocol by the same two evaluators, who were responsible for the evaluation sessions.

6.2.4 RESULTS

The results of the observations and the interview were converted into digital form and analyzed ensuring the security of the participants' personal data. All personal details of the participants (e.g., name, contact details) were not retained in the evaluation. Each piece of information collected was encoded and processed in an anonymous form so that the participants could not be identified. The electronic files with the results were protected by special passwords and all documents with recorded comments and participants' comments, which are in non-electronic form, were kept in a protected area with a key.

6.2.4.1 The overall layout and graphics

Overall, the game's layout and interaction style was well comprehended by all the participants, who although they had played the game just once before, immediately understood where they had to click in order to select an answer, to check their answer and to move to the next step of the recipe. However, one participant was observed to sometimes "forget" to click on the "next" button after the answer, which according to the teacher was a matter of memory problem. Another participant was observed to be insecure and was seeking for teacher's confirmation before clicking on the "next" button.

The answer to the question of whether all children could reach all the interactive elements of the game is positive, since all the children could not only reach all the areas, but they could also close the video playing after each step, which was expected to be closed by the teacher. An interesting observation was that

some children, especially the left-handed, had to change hands during the interaction, in order to better reach the elements on the two sides of the table; fact that should be corrected in the future.

Adding to these observations, none of the participants had any problem in recognizing the graphic representation of the virtual kitchen appliances, ingredients and tools, while all children were able to understand whether an interactive element or area was selected or not. Finally, no problem regarding the textual instructions was noticed, since the text size was found appropriate and the instructions readable by children with adequate reading skills. However, a possible refinement in the textual representation of the step instructions would be if the system could present them piece by piece to the student, separating the various items used for its execution, as the teacher would often do for the participants with lower reading skills. Additionally, the system should repeat the question on demand, each time the instruction box got tapped.

6.2.4.2 Printed cards as a means of interaction

Interaction via cards induced very promising results. None of the children appeared to have any difficulty recognizing the depicted ingredients and tools, while all of them comprehended successfully the “basket” metaphor, placing the respected card inside the card detection area. A possible refinement with respect to interaction via cards in the “Let’s cook” game, would be to provide a second basket for the unused cards, since currently the children used to spread all the cards in front of them, where virtual elements may appear in particular steps of the recipe.

When a card is recognized by the system, it gets surrounded by a virtual square, providing feedback for the detection. All of the students waited for this square to appear before tapping the “next” button, indicating that they understand the connection between the square and the card recognition.

6.2.4.3 Pointing device as a means of interaction

Two different pointing devices were provided with the system, one custom made stamp-shaped device and one stylus. Although the stamp induced very positive results in the first evaluation with the multiple-choice games, that was not the case with the “Let’s cook” game. The device’s design was found too bulky; it completely covered the smaller interactive areas, so the participants could not see where they were tapping, leading to multiple taps before actually selecting an element. Another problem surfaced from this evaluation was that the pressure-sensitive bottom of the stamp was more sensitive than it should be, causing the accidental tapping of certain areas. For instance, when the user wanted to leave the device on the table, the slots underneath it were selected. These problems were not obvious in the first evaluation, since there were less and bigger interactive areas on the table.

These problems were handled with the use of the stylus for the “Let’s cook” game. The stylus, having a smaller pointing edge, is more appropriate for accurate selections in smaller areas. The overall interaction via the stylus was quite satisfactory, given the fact that none of the participants had any serious upper limb limitation. The participants selected the desired elements in a fast, comfortable and accurate way, while they were quite confident in its use.

However, two limitations were observed during the interaction via the stylus; the first was noticed in three of the participants who were left-handed. These participants had difficulty selecting the “next” button, which lays at the bottom right corner of the table. The problem was that their hand pose, inevitably hid the infrared light from the camera, forcing them to use their right hand for this selection. Although they showed no distress from this and performed it naturally, this issue should be addressed in the future.

The second observation was that in two cases, in order to select an element, the user would hit the table quite hard with the stylus and although it worked just fine, it is possible that with this treatment it will not be long before the stylus tip gets broken. To address this issue, a more robust device should be designed and developed as an improved substitute of the stylus.

6.2.4.4 Auditory feedback

There are two different kinds of auditory feedback, both evaluated in this experiment. Firstly, a synthetic voice is used for the pronunciation of the instructions and the advice provided by the system. Five children used the audio instructions as a complementary means of output, because either they could not read or had low reading skills. The instructions were clearly heard and understood by the users, but in cases of more complex sentences, the children seemed to forget the instructions as was also observed in the preliminary evaluation, so the teacher had to repeat them, separated in smaller pieces. The participants showed no particular annoyance about the synthetic voice, however the teacher mentioned in the interview that a physical voice would be better. An interesting observation was that some children were fond of particular instructions, e.g., the “Take your cards from the table” prompt, in which cases they used to repeat it all together and laugh.

The sound effects used to indicate if an answer is correct or not, were also evaluated during the observation sessions. The results indicated that all children could immediately understand their answer’s outcome from the sound feedback, some of them even tried to correct their answer before listening to the system’s advice. Half of the children had a constant positive attitude towards the sounds, while the other half showed no particular feeling, maintaining a neutral approach throughout the game. However, a teacher’s remark during the interview was that for particular children with certain types of autism these sounds may prove to be upsetting, so they will prefer to keep them deactivated.

6.2.4.5 Video as a means of reward and information consolidation

Video for each step was played after its successful execution. Half of the participants had positive attitude towards the video, while the other half demonstrated a neutral reaction. Nonetheless, most of the participants watched the video closely, some commenting on the process and recognizing the RC’s kitchen where the video was taken. In two cases, the participants were impatient, terminating the longer videos prior to their end. A refinement that was suggested by the teacher during the interview was that it would be better for them if there was an extra option in the settings page, stating if the video will be automatically closed or not, since some more advanced children wouldn’t need to watch a video twice.

6.2.4.6 Multimedia output and multimodal interaction

The multimedia output provided by the CocinAR system is, according to the teachers, one of its most important features, fact that was also inferred from the observation sessions. The output modalities varied from child to child, some preferring text output, others auditory, and others their combination. A valuable addition will be the incorporation of the symbol language by the RC's teachers, which is preferred for children with no reading skills.

An important aspect of the CocinAR system, highlighted during the observation sessions, was its ability to serve as a multi-purpose system. More specifically, it was observed that the system was used for practicing not only the student's cooking, but also their reading skills. The educator would deactivate the audio modality for students with good or average level of reading skills, prompting them to read the instructions aloud, thus exercising their reading comprehension.

Regarding the multimodal input, the evaluation experiment showed no major issues. The exchange between the two modes was achieved smoothly and naturally, with the participants understanding when they have to choose a card or use the stylus for selection. Two minor cases were observed, where the participants clicked on the chosen card instead of placing it in the basket, but that was a one-time incident and was corrected by the user themselves without any guidance.

6.2.4.7 System observations

Very specific improvements on certain step types were observed during the sessions and discussed with the educators afterwards. The first observation was on the "Set value" step type, in which the user had to choose a value for the timer. For the selection, all the available values appear in a popup window in a circle layout with a pointer pointing at the selected answer (Figure 24 (b)) and the user is expected to select the correct answer by tapping on the value. Although the tap-to-select approach was considered more suitable for the RC's students, the observation results indicated that ten out of twelve children first tried to drag the pointer to their chosen value rather than clicking on it. According to their teacher, this happened because the physical timer used in the real kitchen follows a drag-to-select approach, which the participants tried to mimic. Given this fact, the type of interaction in this particular step should be transformed into a drag-to-select model. No similar issues were observed for the other step types.

Room for improvement was also observed in the "Repeat" step type. This step type indicates that the student must repeat a certain action for a specific number of times. For instance, in the "Put three cups of water in the pot" step, the student must choose the cup, the faucet and the pot three times in a row. In every repetition, a counter element increments its value, depicting the completed repetitions with green boxes and the remaining with gray (Figure 24 (a)). However, the repetition representation was not clear to nine out of twelve the children, who would turn to their teacher for instructions after the first execution. A refinement that would enhance the comprehension of the repetition, according to the teacher, would be to depict the item that is used multiple times (in this case the cup), next to each box of the counter element, along with the number of the repetitions inside each box. In addition,

complementary audio feedback should be provided, informing the student how many repetitions are already executed and how many are left. For low functionality students it was suggested to place the appropriate number of graphic elements that will be used for the repetition on the table (e.g., three cups), making it easier for children to understand that they have to interact repeatedly with the specific element.

Lastly yet importantly, it was observed in some “Combine” type steps that the users often forgot to select the means necessary for the step’s execution. For instance, in the “Put butter in the pasta” step, the user had to select the pasta, the butter, but also the spoon for putting the butter in the pasta, which was not obvious from the instruction. In these cases, when the missing item is the medium, the system should ask the student a question like “How are you going to put the butter in the pasta?” rather than “You need one more item”.

6.2.4.8 Teacher comments

The information derived from the interview complemented and verified the data collected from the observation sessions. The teacher highlighted the importance of the CocinAR’s incorporation in their everyday classes as a tool for mental consolidation of the meal preparation process and believed that the frequent use of the system will contribute to the memorization of the steps’ sequence, which is the goal of their training. Another statement was that the students could easily learn how to play the game, just by looking other children play, so even from their first time they could comprehend the layout of the game. As it was also observed during the observation, all participants used to gather around the table and sit patiently throughout all the sessions of the day, congratulating and clapping when the one who played completed the recipe. The overall approach towards the system was positive, the students seemed to like it very much and the teacher, when asked, confirmed that observation quoting “Yes! Very much!”.

6.2.4.9 Data analysis

Quantitative data were also recorded during the observation sessions, aiming to produce statistical indications about possible interaction problems. More specifically, a form was completed for each step, including the correctness of the user’s answer, the kind of mistakes made and the user’s ability to move to the next step. Pursuing a structured data record, all recipe’s steps were analyzed according to their interaction type described in Section 5.6.4.1. In summary, each step is included in one of the following categories:

1. Card – Refers to the retrieval steps, in which the user brings a card on the table.
2. Single selection – Refers to the turn on/off functionality, where the user just clicks on the respected kitchen appliance.
3. Move – Refers to the steps that a virtual item is moved to another slot. For this step’s execution, the user clicks on the virtual item and the preferred slot (e.g. “Put the pot on the stoves”).
4. Combine – The Combine type refers to all the steps in which any kind of mixing of virtual objects is necessary (e.g. “Put the milk in the cup” or “Cut the onion on the cutting board”).

5. Repeat – Is basically a Combine step, which is repeated for a specific number of times (e.g. “Put three cups of water inside the pot”).
6. Set Value – The switching of a kitchen appliance to a specific value, is accomplished through a custom button, which displays all the available options and the user selects the preferred one (e.g. “Set the timer to 8 minutes”).
7. Wait – Refers to the steps in which the user waits for a process to end (“Wait for the water to boil”). No action is required for this kind of steps, the system proceeds automatically to the next step when a timer animation ends.

The total number of each student’s committed errors and the helps provided by the teacher are depicted in Figure 32. The errors and helps for each student, demonstrating that in general, the teacher would first wait for the child to execute each step by its own and provide help was afterwards, if necessary. In some cases the child would correct the mistake without any guidance, while in others the teacher would guide the student by asking key questions.

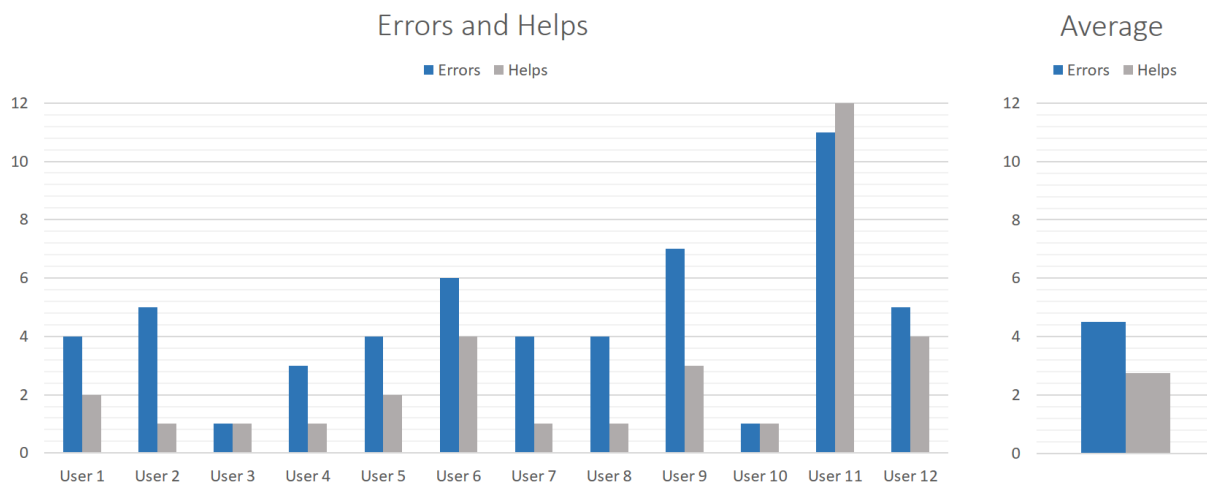
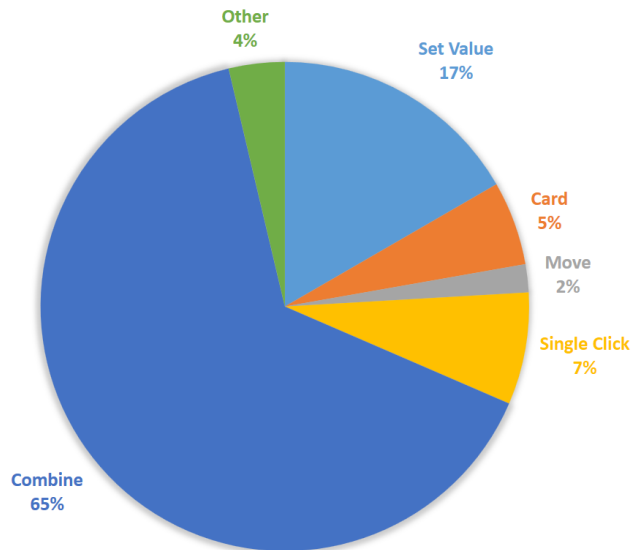


Figure 32. The errors and helps for each student

Table 5. The matrix of the total errors and helps of each student, along with their average and standard deviation values.

User	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10	U11	U12	AVG	STDEV
Errors	4	5	1	3	4	6	4	4	7	1	11	5	4.5	2.46
Helps	2	1	1	1	2	4	1	1	3	1	12	4	2.75	3.13

ERROR ANALYSIS



Step Type	Total Errors	% Errors
Set Value	9	16.67
Card	3	5.56
Move	1	1.85
Single Click	4	7.41
Combine	35	64.81
Other	2	3.7

Figure 33. Errors committed in each step type

An interesting result derived from the observation sessions is the percentage of errors in each step type. As seen in Figure 33, most errors were noticed in the Combine steps, with great difference from the other categories. The majority of these errors were resolved when the teacher would read the sentences piece by piece to the children, in which case they could easily locate and select the requested items. This phenomenon indicates that the correct execution of a step was not inhibited by the users' inability to interact with the system, but due to difficulty in comprehending and remembering long instructions. To address this issue, the system could present the long instructions gradually, pausing after each asked item until it is successfully selected, and reveal the next part of the sentence afterwards.

The most usual error committed in the Combine steps was the “Missing Item” error, in which the student failed to select all the items necessary for the step completion. It is interesting to note that when a “Utensil” item was implied by the instruction (e.g., in the “Put butter in the pasta” step, the pasta, butter, but also the spoon had to be selected), the student would miss it in the 50% of the questions, while only in the 3% when all items were clearly stated (Figure 34). Again, this metric suggests that children had no problem with the action of executing a recipe step, but rather with the instruction’s presentation, which have been defined by the RC’s educators appropriately, in order to serve their current teaching goals.

Table 6. Percentages of “Missing Item” errors when an item is implied versus when all items are clearly stated.

User	% of implied items' misses	% of clearly stated items' misses
User 1	75%	0
User 2	25%	12.5%
User 3	0	0
User 4	50%	0
User 5	50%	0
User 6	50%	0
User 7	50%	12.5%
User 8	50%	0
User 9	50%	0
User 10	25%	0
User 11	100%	12.5%
User 12	75%	0
Average	50%	3%
Standard deviation	0.2	0.056

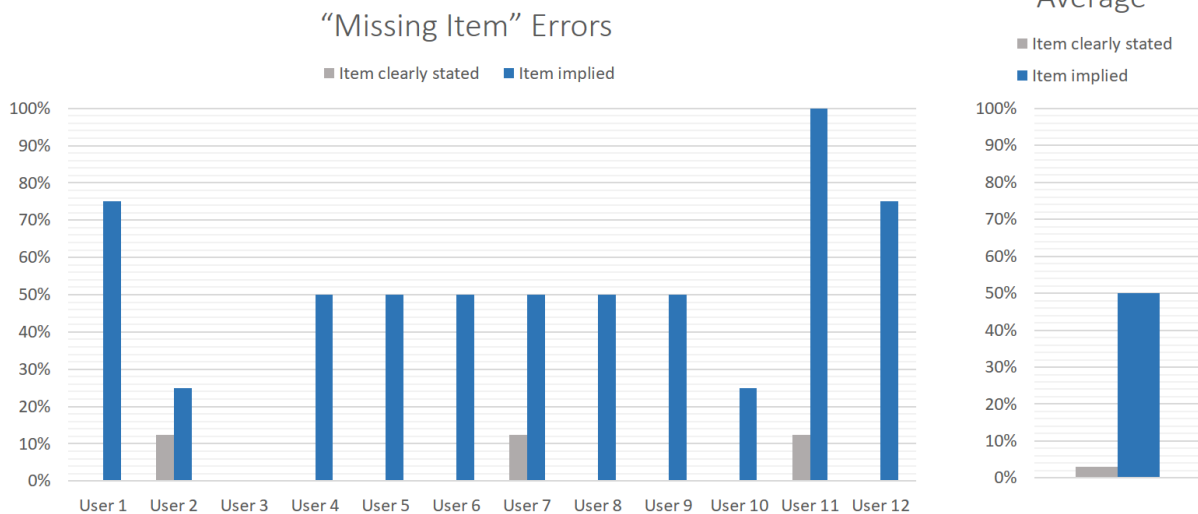


Figure 34. “Missing Item” errors when an item is implied versus when all items are clearly stated.

In an attempt to distinguish the mistakes related to interaction problems from the ones originating from cognition difficulties, all observed errors were categorized as shown in Table 7. Two conclusions can be derived from this table; the “Missing item” phenomenon described earlier and the tendency of the children to drag the pointer to the preferred value instead of clicking on it in the “Set value” steps. The second observation refers to an obvious interaction problem, which can be resolved by supporting dragging functionality for this particular step. Moreover, the error analysis indicated that the 24% of the total mistakes were attributed to interaction problems, while the 76% were cognition-related errors.

Table 7. Error categorization. The last three error types refer to interaction problems.

Errors	Usr 1	Usr 2	Usr 3	Usr 4	Usr 5	Usr 6	Usr 7	Usr 8	Usr 9	Usr 10	Usr 11	Usr 12
Extra selection			1				1	1				
Wrong selection		2			1	2			2		2	
Wrong card											2	
Missed implied Item	3	1		2	2	2	2	2	2	1	4	3
Missed stated item		1					1				1	
Clicked the card									1		1	
Dragged to set value	1	1		1	1	1		1	1		1	1
Other						1						1

6.2.5 LIMITATIONS

The assessment of the educational value of the system and its actual effectiveness in terms of facilitating learning for children with cognitive impairments requires an extensive and long-term evaluation, which was not possible in the context of this thesis. This evaluation would be a controlled experiment, involving a group of children who would learn a recipe utilizing the system in their training and a second group who would learn the same recipe without it.

Another limitation faced in this evaluation had to do with the range of the functionality levels examined. The system was recently installed in the RC and the RC’s symbol language was not yet incorporated in the system, so lower functional children, for whom symbol language is necessary, could not participate in the experiment. In the future evaluation rounds scheduled, the symbol language will be incorporated in the system, overcoming this limitation.

Finally, the statistical data collected by the system did not cover sufficient time range for solid indications to be extracted and used by the current evaluation experiment. However in the long run, the system’s logs may constitute a valuable source of information for research purposes.

6.3 DISCUSSION

The evaluation of the CocinAR system aimed to determine the answers to specific research questions regarding its usability and suitability for the particular educational purpose. A general conclusion based on the results of both evaluations is that the participants had no problem comprehending the layout of the game and the overall style of interaction. They knew where to expect the various elements to appear and what they had to do in order to check their answer and move to the next step. The graphic elements were proved appropriate for all the participating children and they could understand whether an item is selected or not. An improvement regarding the overall layout would be to provide an additional option, allowing the “next” button to be displayed at the left corner of the table, in order to facilitate the interaction of the left-handed children.

Regarding the input multimodality, it was a pleasant surprise to see how naturally all children could switch between the two interaction styles. They comprehended immediately the “fetch” paradigm of the card retrieval steps and could recognize the ones that required interaction via the stylus. The multimedia output was verified as a necessary part of the system, facilitating a personalized content provision, able to meet the students’ diverse needs and dexterities. Moreover, the multimedia output allowed the practice of additional, apart from cooking, skills, such as reading and listening comprehension, granting a multi-purpose character to the system.

Another important outcome was that the interaction with each virtual element used in the system should match exactly and in detail the style of interaction with the corresponding physical element used in the RC’s kitchen. In any different case, the children would be confused, as was indicated by the “Set Value” step, in which the students would drag the virtual timer’s pointer to the selected value, as they do with the real timer, rather than click on it. Furthermore, a difficulty in the comprehension of long sentences was observed, leading to the suggestion that the system should be able to present long instructions gradually, pausing after each requested item until it is successfully selected to reveal the next part of the sentence. Another issue related to instructions’ presentation was observed in the steps where the medium necessary for the step was implied rather than clearly stated, so the students were likely not to select it. To address this issue, the system could help the student by asking an indicative question, currently asked by the teacher.

It is worthy to mention that prior to the final user-testing evaluation in the RC that involved children with cognitive impairments, UX experts also examined the “Let’s cook” game for usability issues. The interesting fact was that the UX experts were worried about more problems than actually appeared in the observation sessions, since the children could easily execute the various steps of the recipe by themselves, although having played it just once before the evaluation experiment.

The fundamental question of whether the children actually liked the system was answered both by the teacher and also by the observed behavior of the children. According to the educators, any digital form of information is appealing to their students, even a simple PowerPoint presentation, keeping them focused to the task at hand. Moreover, the educators consider this kind of exercises important for the better cognitive comprehension of the recipe, bringing them closer to their educational goal, i.e., its complete memorization. That said, it was clear from the evaluation experiment that the interaction with CocinAR enriches the user experience, making it more engaging for children and thus facilitates the educational purpose of their teachers.

7 CONCLUSIONS & FUTURE WORK

A common problem among people with cognitive impairments is self-management and carrying out everyday tasks, such as bathing, eating, preparing simple meals, etc. Meal preparation is a skill that is considered important to teach to individuals with cognitive disabilities in order to increase their independence. To that end, CocinAR is an AR educational system that was developed to enhance the independence of children with cognitive impairments by cultivating basic cooking skills.

CocinAR incorporates various educational games aiming to get children with cognitive impairments acquainted with elementary meal preparation notions, while employing novel input methods through cards and pointing devices on a tabletop surface. Multimodality of content representation is also one of the fundamental features of CocinAR, ensuring that the system is usable by children with cognitive impairments with diverse needs and dexterities. In addition, the supported profiling functionality allows for system personalization and adaptability to each child's preferences, while providing statistic information valuable to the teachers on the progress of each student's skills.

The usability evaluation conducted after the final installation of the system, which involved children with cognitive impairments, indicated positive results and revealed potential future refinements for the system. The graphics and the overall layout of the interactive elements were well comprehended by all children, contributing to their confident and autonomous interaction with the system. Regarding the tangible interaction, the printed cards method was used comfortably and intuitively on the tabletop surface, while the interaction via the infrared stylus was overall fast and accurate. Moreover, switching between the two modes was achieved smoothly and naturally, with the participants understanding when they have to choose a card or use the stylus for selection. The fundamental question of whether the children actually liked the system was answered positively by both the teacher's comments and the observed behavior of the children.

As a next step, the refinements and adaptations emerged from the evaluation will be implemented and a new, improved version of CocinAR will be installed at the RC. One major improvement would be the symbol language incorporation into the system, which will definitely upgrade the user experience of non-reading children. Moreover, the system will be adapted to enhance the interaction of the left-handed students by providing configurability in the positioning of the buttons. Furthermore, adaptations to certain recipe steps will be made, aiming to better represent the real interaction in the RC kitchen.

Regarding the tangible input, the printed cards were found to be a very comfortable method when it comes to tabletop interfaces, presenting no problems whatsoever. The custom pointing device, although it was found intuitive and comfortable in its use during the multiple-choice games, proved unsuitable for the interaction with the "Let's cook" game, in terms of accuracy and comfort. The stylus, on the other hand, was verified as an appropriate means of input in the "Let's cook" game, requiring however some

modifications in the structure of the current device, making it more durable. In the future, a new custom made infrared pointing device will be designed, 3D-printed and given to the RC.

In addition, future work will include extensive and long-term evaluation, aiming to assess the educational value of the system and its actual effectiveness in terms of facilitating learning for children with cognitive impairments. This evaluation is planned to be a controlled experiment, involving a group of children who will learn a recipe utilizing the system in their training and a second group who will learn the same recipe(s) without it. The statistic information kept by the system will also be analyzed in this respect, in order to produce some indications regarding the long-term progress of the children in their performance in the games, as well as to identify potential problems of the system in terms of content or interaction.

Apart from improvements on existing aspects of CocinAR, future work will deal with adaptation of the system to the needs of each user. Adaptation as currently supported by the system involves static adaptation to the interaction preferences of each user. Future developments will also take into account each individual's progress with regard to specific learning goals, with the aim to personalize the actual displayed content, automatically and at runtime.

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APPENDIX I – PRELIMINARY EVALUATION OBSERVATION PROTOCOL

Date:	Observer:	Teacher:	
User condition:	Functionality level:	Age:	Sex:

Overall, physical setup evaluation	
Could the child reach all the interaction elements displayed on the table easily?	<input type="checkbox"/> Yes <input type="checkbox"/> No (due to design) <input type="checkbox"/> No (due to the cognitive impairment) <input type="checkbox"/> Somewhat. Explain:
Could the child see all graphical and textual elements of the game easily?	<input type="checkbox"/> Yes <input type="checkbox"/> No (due to design) <input type="checkbox"/> No (due to the cognitive impairment) <input type="checkbox"/> Somewhat. Explain:
Could the child hear (not understand) when the system spoke the question?	<input type="checkbox"/> Yes <input type="checkbox"/> No (due to design) <input type="checkbox"/> No (due to the cognitive impairment) <input type="checkbox"/> Somewhat. Explain:
Did the child distinguish the sound for the right answer vs the sound for a wrong answer?	<input type="checkbox"/> Yes <input type="checkbox"/> No (due to design) <input type="checkbox"/> No (due to the cognitive impairment) <input type="checkbox"/> Somewhat. Explain:
How did the child react to the above sound?	Describe:

Usability	
Did the child seem to understand the overall spatial layout of the games? (i.e., where he/she had to click in order to pick an answer, know where to expect the next question or the solution to appear, etc.)	<input type="checkbox"/> Yes <input type="checkbox"/> No (due to design) <input type="checkbox"/> No (due to the cognitive impairment) <input type="checkbox"/> Somewhat. Explain:
Did the child seem to understand the goal of each game? (i.e., what was expected of them to do during the game)	<p>Game 1:</p> <input type="checkbox"/> Yes <input type="checkbox"/> No (due to design) <input type="checkbox"/> No (due to the cognitive impairment) <input type="checkbox"/> Somewhat. Explain:
	<p>Game 2:</p> <input type="checkbox"/> Yes <input type="checkbox"/> No (due to design) <input type="checkbox"/> No (due to the cognitive impairment) <input type="checkbox"/> Somewhat. Explain:
	<p>Game 3:</p> <input type="checkbox"/> Yes <input type="checkbox"/> No (due to design) <input type="checkbox"/> No (due to the cognitive impairment) <input type="checkbox"/> Somewhat. Explain:
Could the child move from question to the next question autonomously (without the help of the teacher)?	<input type="checkbox"/> Yes <input type="checkbox"/> No (due to design) <input type="checkbox"/> No (due to the cognitive impairment) <input type="checkbox"/> Somewhat. Explain:
Did it learn easily how to select the correct answer?	<input type="checkbox"/> Yes <input type="checkbox"/> No (due to design) <input type="checkbox"/> No (due to the cognitive impairment) <input type="checkbox"/> Somewhat. Explain:

Could the child use the pointer device with accuracy?	<input type="checkbox"/> Yes <input type="checkbox"/> No (due to design) <input type="checkbox"/> No (due to the cognitive impairment) <input type="checkbox"/> Somewhat. Explain:
If cards were used, did the child know where to place the cards in order for the system to read them correctly?	<input type="checkbox"/> Yes <input type="checkbox"/> No (due to design) <input type="checkbox"/> No (due to the cognitive impairment) <input type="checkbox"/> Somewhat. Explain:
Was the overall organization of the content of the game easily understood by the child?	<input type="checkbox"/> Yes <input type="checkbox"/> No (due to design) <input type="checkbox"/> No (due to the cognitive impairment) <input type="checkbox"/> Somewhat. Explain:
Overall Interaction	
How would you describe the child's overall reaction to the system during his/her interaction with it;	<input type="checkbox"/> confident <input type="checkbox"/> insecure <input type="checkbox"/> curious <input type="checkbox"/> bored <input type="checkbox"/> autonomous <input type="checkbox"/> waits for instructions <input type="checkbox"/> focused <input type="checkbox"/> chaotic <input type="checkbox"/> patient <input type="checkbox"/> impatient <input type="checkbox"/> stressed <input type="checkbox"/> relaxed <input type="checkbox"/> over stimulated <input type="checkbox"/> apathetic <input type="checkbox"/> engaged <input type="checkbox"/> indifferent <input type="checkbox"/> happy <input type="checkbox"/> sad/scared <input type="checkbox"/> neutral Details:
Was the initial reaction of the child toward the system constant throughout the entire session?	<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Only at the beginning and it then started fading as the child got oriented
Which games were played?	<input type="checkbox"/> Πότε το τρώμε επίπεδο: <input type="checkbox"/> Βρες τα υλικά επίπεδο: <input type="checkbox"/> Βρες τα σκεύη επίπεδο: <input type="checkbox"/> Ποια είναι η σωστή συμπεριφορά επίπεδο:

Technical Issues
Pointer performance:
Cards performance:
Crashes, lags, frozen screens, etc.:
Other unexpected behavior:

Notes:

APPENDIX II – EXTENSIVE EVALUATION OBSERVATION PROTOCOL FOR CHILD’S OVERALL INTERACTION

User condition:

Functionality level:

User age:

Teacher:

Recipe:

Game-Play																						
Did the child seem to understand the overall layout of the game? (i.e., where he/she had to click in order to pick an answer, know where to expect the next question or the solution to appear, etc.)	<input type="checkbox"/> Yes <input type="checkbox"/> No. Explain: <input type="checkbox"/> Somewhat. Explain:																					
Could the child reach all the interaction elements displayed on the table easily?	<input type="checkbox"/> Yes <input type="checkbox"/> No. Explain:																					
Interaction																						
Student could easily find/handle the card he/she wanted	<input type="checkbox"/> Yes <input type="checkbox"/> No: The student couldn’t cope with the big number of cards <input type="checkbox"/> No: The cards were difficult to catch/hold <input type="checkbox"/> No: Other:																					
Interaction with the pointer device	<table style="width: 100%; border: none;"> <tr> <td><input type="checkbox"/> Comfortable</td> <td><input type="checkbox"/> Uncomfortable</td> </tr> <tr> <td><input type="checkbox"/> Accurate (correct item)</td> <td><input type="checkbox"/> Inaccurate</td> </tr> <tr> <td><input type="checkbox"/> Intuitive</td> <td><input type="checkbox"/> Counter-intuitive</td> </tr> <tr> <td colspan="2"><input type="checkbox"/> Other:</td> </tr> </table>	<input type="checkbox"/> Comfortable	<input type="checkbox"/> Uncomfortable	<input type="checkbox"/> Accurate (correct item)	<input type="checkbox"/> Inaccurate	<input type="checkbox"/> Intuitive	<input type="checkbox"/> Counter-intuitive	<input type="checkbox"/> Other:														
<input type="checkbox"/> Comfortable	<input type="checkbox"/> Uncomfortable																					
<input type="checkbox"/> Accurate (correct item)	<input type="checkbox"/> Inaccurate																					
<input type="checkbox"/> Intuitive	<input type="checkbox"/> Counter-intuitive																					
<input type="checkbox"/> Other:																						
Child’s behavior																						
How would you describe the child’s overall reaction to the system during his/her interaction with it;	<table style="width: 100%; border: none;"> <tr> <td><input type="checkbox"/> confident</td> <td><input type="checkbox"/> insecure</td> <td rowspan="10" style="vertical-align: top; padding-left: 20px;">Details:</td> </tr> <tr> <td><input type="checkbox"/> curious</td> <td><input type="checkbox"/> bored</td> </tr> <tr> <td><input type="checkbox"/> autonomous</td> <td><input type="checkbox"/> waits for instructions</td> </tr> <tr> <td><input type="checkbox"/> focused</td> <td><input type="checkbox"/> chaotic</td> </tr> <tr> <td><input type="checkbox"/> patient</td> <td><input type="checkbox"/> impatient</td> </tr> <tr> <td><input type="checkbox"/> stressed</td> <td><input type="checkbox"/> relaxed</td> </tr> <tr> <td><input type="checkbox"/> over stimulated</td> <td><input type="checkbox"/> apathetic</td> </tr> <tr> <td><input type="checkbox"/> engaged</td> <td><input type="checkbox"/> indifferent</td> </tr> <tr> <td><input type="checkbox"/> happy</td> <td><input type="checkbox"/> sad/scared</td> </tr> <tr> <td></td> <td><input type="checkbox"/> neutral</td> </tr> </table>	<input type="checkbox"/> confident	<input type="checkbox"/> insecure	Details:	<input type="checkbox"/> curious	<input type="checkbox"/> bored	<input type="checkbox"/> autonomous	<input type="checkbox"/> waits for instructions	<input type="checkbox"/> focused	<input type="checkbox"/> chaotic	<input type="checkbox"/> patient	<input type="checkbox"/> impatient	<input type="checkbox"/> stressed	<input type="checkbox"/> relaxed	<input type="checkbox"/> over stimulated	<input type="checkbox"/> apathetic	<input type="checkbox"/> engaged	<input type="checkbox"/> indifferent	<input type="checkbox"/> happy	<input type="checkbox"/> sad/scared		<input type="checkbox"/> neutral
<input type="checkbox"/> confident	<input type="checkbox"/> insecure	Details:																				
<input type="checkbox"/> curious	<input type="checkbox"/> bored																					
<input type="checkbox"/> autonomous	<input type="checkbox"/> waits for instructions																					
<input type="checkbox"/> focused	<input type="checkbox"/> chaotic																					
<input type="checkbox"/> patient	<input type="checkbox"/> impatient																					
<input type="checkbox"/> stressed	<input type="checkbox"/> relaxed																					
<input type="checkbox"/> over stimulated	<input type="checkbox"/> apathetic																					
<input type="checkbox"/> engaged	<input type="checkbox"/> indifferent																					
<input type="checkbox"/> happy	<input type="checkbox"/> sad/scared																					
	<input type="checkbox"/> neutral																					

Was the initial reaction of the child toward the system consistent throughout the entire session?	<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Only at the beginning and it then started fading as the child got oriented	
What was the reaction of the child toward the sound ?	Wrong	Right
	<input type="checkbox"/> Disappointment about mistake <input type="checkbox"/> Annoyance about the sound	<input type="checkbox"/> Joy about sound <input type="checkbox"/> Annoyance about the sound
	<input type="checkbox"/> consistent throughout the entire session	
What was the reaction of the child toward the video ?	<input type="checkbox"/> Positive <input type="checkbox"/> Negative	<input type="checkbox"/> Enthusiasm <input type="checkbox"/> Indifference
	<input type="checkbox"/> consistent throughout the entire session	

After Session

Any comments on today's session compared to previous?

Notes:

APPENDIX III - EXTENSIVE EVALUATION OBSERVATION PROTOCOL BY STEP

Observation Protocol - step

Observer:

Date:

Time:

Step #__				Type: <input type="checkbox"/> Card <input type="checkbox"/> Single <input type="checkbox"/> Move <input type="checkbox"/> Combine <input type="checkbox"/> Repeat <input type="checkbox"/> Set Value			
No Action	Card Errors		Click Errors	Move to next step			
<input type="checkbox"/> Didn't know answer <input type="checkbox"/> Didn't understand question <input type="checkbox"/> Didn't know what to do	Wrong card #__	Placement	Wrong elem #__	<input type="checkbox"/> Yes <input type="checkbox"/> with teacher prompt <input type="checkbox"/> with teacher guidance			
	Which:		Which:				
	<input type="checkbox"/> Didn't know answer <input type="checkbox"/> Didn't understand question <input type="checkbox"/> Couldn't find card <input type="checkbox"/> Misunderstood card's graphic	<input type="checkbox"/> Yes <input type="checkbox"/> With prompt <input type="checkbox"/> With guidance	<input type="checkbox"/> Didn't know answer <input type="checkbox"/> Didn't understand question <input type="checkbox"/> Didn't know it was clickable <input type="checkbox"/> Couldn't find element				
Notes:							

APPENDIX IV - EXTENSIVE EVALUATION TEACHER INTERVIEW DOCUMENT

1. Are the graphic components suitable for all the students?
 - a. If not, what problem was observed and how could it be fixed?

2. Is the interaction via cards suitable for all the students?
 - a. If not, what problem was observed and how could it be fixed?

3. Is the interaction via the pointing devices suitable for all the students?
 - a. If not, what problem was observed and how could it be fixed?

4. Is the use of the “stamp” comfortable? (breaks, charging etc.)

5. Is the text to speech service suitable for all the students?
 - a. If not, what problem was observed and how could it be fixed?

6. Are the sound effects used suitable for all the students?
 - a. If not, what problem was observed and how could it be fixed?

7. Is the video feature suitable for all the students?
 - a. If not, what problem was observed and how could it be fixed?

8. Did the system increase the students’ attitude towards cooking?

9. Does the system help you to achieve your teaching goals for each student?
 - a. If yes, how?
 - b. If not, why?

10. Do the children like the system?