Universidade do Minho
Escola de Engenharia

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The impact of Augmented Reality for training Computational Thinking

Março de 2024

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Lázaro Vinícius de Oliveira Lima

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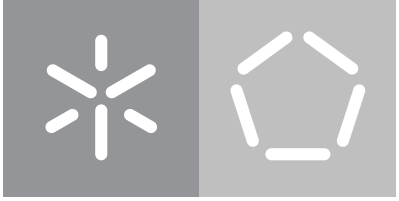


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March, 2024



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The impact of Augmented Reality for training Computational Thinking

Doctoral Thesis

Doctorate in Informatics

Work supervised by

Pedro Rangel Henriques

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March, 2024

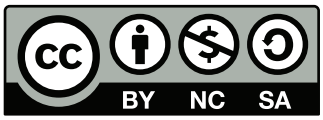
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Este trabalho dedico a minha querida família, meu pai Valtuir e minha mãe Lais, que com suas palavras, me guiaram sempre para conhecimento. Foram sempre palavras de incentivos e superação. A minha amada Lorena, por me apoiar em tempos que fomos obrigados a ficar distantes para conquistarmos nossos objetivos. Minha amada irmã Thaisa e família, que me apresentou a Universidade do Minho e me abriu os horizontes, sou eterno grato. Sem esquecer dos meus queridos sobrinhos, Issac e Samuel. Ao meu querido amigo Ernesto que sem ele não haveria esse trabalho. Obrigado meu amigo. Aos meus amigos, Charles Coragem, Manuel Soares, João Pedro Scout, José Simão e Ivo Lima, que nas horas mais desesperançosas, me deram força e ajuda na minha jornada. Pedro Rangel Henriques, meu orientador que foi mais que isso, pessoa essa que nasceu pra exercer a docência com empatia e muito amor. Obrigado a todos aqueles que de alguma forma, enviaram suas boas energias.

Abstract

This thesis demonstrates how the requirements of an educational resource can be organized to explore the potential of Computational Thinking (CT) in conjunction with visualization techniques and Augmented Reality. We developed systems and conducted experiments to support our thesis and published work on Learning Resources (LR) for learners to train the skills that characterize the CT and allow for solving problems. The goal of this Ph.D. work is to provide a better understanding of how to effectively explore and understand how AR can help in the task of Computer Programming. To find a formal support to design and develop the referred LR, and also to conduct the final experiments, an ontology (OntoCnE) was used to characterize the domains of Computer Programming and Computational Thinking. This doctoral project is intended to demonstrate that creating adequate AR-based tools to train CT can aid in better understanding, analyzing, and solving problems in a digital society. The development of Computational Thinking skills requires the creation and use of appropriate educational resources. One of the main focus of this work was the teaching and learning of Computational Thinking in schools. The impact of AR on this process was investigated aiming at creating resources that can improve fundamental skills in an attractive way for students. With AR it was also possible to demonstrate the effects that a program performs on the state of the system with a tool that assists in the visualization of the behavior of data structures while executing the program operations. It is believed that individuals acquire new ways of thinking or behaving through appropriate learning resources. Therefore, a significant investment in educating young people in Computational Thinking is necessary. The Learning Resources proposed and discussed in the thesis are intended to train CT skills and provide visual representations and interactivity to engage students. To evaluate the effectiveness of the approach, some questionnaires were applied before and after using the Learning Resources enhanced with AR. Finally, the impact of the approach was assessed in school teaching environments.

Keywords: Augmented Reality, Learning Resource, Active Learning, Mobile Learning, Computational Thinking,

Resumo

Esta tese demonstra como os requisitos de um recurso educativo podem ser organizados para explorar o potencial do Pensamento Computacional em conjunto com técnicas de visualização e Realidade Aumentada. Desenvolvemos sistemas e conduzimos experiências para apoiar a nossa tese, tendo publicado trabalhos sobre Recursos de Aprendizagem para estudantes treinarem as competências que caracterizam o Pensamento Computacional e que permitem resolver problemas. O objetivo deste trabalho de doutoramento é proporcionar um melhor entendimento de como explorar eficazmente e compreender como a Realidade Aumentada pode auxiliar na tarefa de Programação de Computadores. Para encontrar um suporte formal para projetar e desenvolver o referido Recurso de Aprendizagem, e também para conduzir as experiências finais, foi utilizada uma ontologia (OntoCnE) para caracterizar os domínios da Programação de Computadores e do Pensamento Computacional. Este projeto de doutoramento pretende demonstrar que a criação de ferramentas adequadas baseadas em Realidade Aumentada para treinar o Pensamento Computacional pode auxiliar na compreensão, análise e resolução de problemas numa sociedade digital. O desenvolvimento das competências de Pensamento Computacional requer a criação e utilização de recursos educativos apropriados. Um dos principais focos deste trabalho foi o ensino e aprendizagem do Pensamento Computacional nas escolas. O impacto da Realidade Aumentada neste processo foi investigado com o objetivo de criar recursos que possam melhorar competências fundamentais de uma forma atrativa para os estudantes. Com a Realidade Aumentada, foi também possível demonstrar os efeitos que um programa realiza no estado do sistema com uma ferramenta que auxilia na visualização do comportamento das estruturas de dados durante a execução das operações do programa. Acredita-se que os indivíduos adquirem novas formas de pensar ou comportar-se através de recursos de aprendizagem apropriados. Portanto, um investimento significativo na educação dos jovens em Pensamento Computacional é necessário. Os Recursos de Aprendizagem propostos e discutidos na dissertação têm como objetivo treinar competências de Pensamento Computacional e fornecer representações visuais e interatividade para envolver os estudantes. Para avaliar a eficácia da abordagem, foram aplicados questionários antes e após a utilização dos Recursos de Aprendizagem aprimorados com Realidade Aumentada. Por fim, o impacto da abordagem foi avaliado em ambientes de ensino escolar.

Palavras-chave: Realidade Aumentada, Recurso de Aprendizagem, Aprendizagem Ativa, Aprendizagem Móvel, Pensamento Computacional.

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Chapter 1

Introduction

Nowadays we need to adopt new strategies that promote in the students the development of fundamental skills like reading, writing, arithmetic, or analytic capabilities. These skills are crucial for many activities that in general require Problem-Solving capabilities as is the case of Computer based tasks which demand Computational Thinking (CT) ability. In that direction, CT shall be included as a fundamental skill in the primary and secondary school curricula. The aim of such a decision is to develop in the students competences for problem-solving that will be required for the citizens of the 21st century. To train and induce in the students CT, a new teaching/learning process must be devised using techniques derived from Mathematics, Gaming, and Computer Science. The abilities that characterize CT—like logic reasoning, abstraction, rigor in analysis and specification, strategic planning, etc.—are of uttermost relevance in Programming. Technology provides broad access to information and knowledge, but nowadays it is used mostly focusing only on access to social networks, games, music, production, and exchange of images among students. Generally, these same students are not able to perform a simple Internet search, though they constantly use these connected devices to exchange information. Digital Literacy is a term used to define different levels of reading and writing ability that an individual has of technology; there are computer literate users who only know how to use basic features but who differ from computer literates in the sense in which they are those who know how to explore the resources of technologies. The concept of digital competence was proposed by the European Parliament and the Council of the European Union in 2006 as the constant and critical use of Information Society Technology for work, leisure, and communication (Council, 2006). One of the strongest reasons that shows the importance of CT for learning Computer Programming (CP) is presented in the book of Aho and Ullman (1992), where the authors state that through the techniques coined to CT it is possible to explore the abstraction of students capable of scaling and dealing with complexity.

In order to understand how to deal with the digital culture, it is necessary to have knowledge related to:

- How computers and their technologies work;
- How data representation occurs in the digital world;
- The difference between Hardware and Software;
- What is the conceptual transmission of information through networks.

Because these terms are similar in their characteristics, they are not conflicting and indicating that there is still room for the implementation of new policies for deploying technologies in education (Valente, 2019). The understanding of the difference between Computational Literacy, Computational Thinking, and Digital Competence and their interconnections, helps to understand the concepts for establishing policies on the deployment of teaching technologies.

Wing (2006) states that is fundamental to the development such as reading, writing, arithmetic, and analytical abilities in students. CT is a teaching/learning process that uses various techniques derived from Computer Science to develop competences in students. CT is the way we organize thoughts to solve a problem (Wing, 2014).

With the spread of Information and Communication Technologies (ICT), the technology for children is ordinary. Students connected with screens of devices with natural interaction is a common scenario nowadays, allowing for natural handling of technological environments. The impact of programming languages to stimulate the development of knowledge has already been mentioned by DiSessa (2001) in previous research, but the concept of CT became popular with Wing in her article Wing (2014), saying that CT is a fundamental skill as reading, writing, and arithmetic and analytical capacity to be developed in students. In terms of the use of technological resources, in order to introduce the concepts of programming languages, it is important to pay attention that they must be able to motivate and encourage students, to develop abstraction, decomposition of problems and to identify and organize the steps to solve a problem. Moreover, they should allow a constructivism-based teaching approach, that has been proved to promote effective knowledge acquisition. This ability can be developed by inserting courses in the curriculum using technology to promote digital literacy or courses that explore the concepts of CP through games, robotics, or even cross-sectional. These skills are related to better communication and problem-solving in all aspects of life. These artifacts are often available in the school environment; they help improve the quality and innovation of the teaching-learning process.

To explore and create tools and activities to train the CT, Augmented Reality(AR), was chosen as the main approach for this Ph.D. work aiming at coming up with a novelty.

The first definitions of Augmented Reality are described in the Survey by Azuma (1997) defined as the overlapping of virtual information in the real world through technology. This information can be simple textual images or 3D objects that can perform interactions with such objects. AR is the enrichment of the real world with virtual objects, texts, images, graphics, and sounds, using a technological device and running in real time. Virtual Reality consists of the simulation of virtual scenes, raising the user to an

experience of immersion and interaction in a virtual world based on simulation generated by a computer, as illustrated in Figure1.1.



Figure 1.1: AR Example with virtual object superimposed in the real world

1.1 Motivation

Humanity is all the time reinventing the ways of teaching looking for new means to execute the necessary knowledge transference process. The use of new technologies to develop student's essential skills provides greater motivation and engagement among them. In this context, AR is being used in education through systems that range from the simple projection of a pulsating virtual heart in a biology class to professional training where the user can be guided with virtual information presented in his field of vision with different equipment.

Research in education supported by augmented reality (AR) focuses mainly on the importance of the teacher as the person responsible for facilitating interaction among students. The teacher is the one who instructs students on how to learn a particular subject or skill.

There is a great need to investigate the development of CT, which teachers seek to stimulate in early stage students by introducing the concepts of logic, abstraction, and the ability to solve problems. In a previous work Lima et al. (2013), a system to assist therapists in the treatment of phobias through virtual object exposition using user-focused Requirements Engineering strategies (Nakamoto et al., 2012) was developed. In that project, it has been realized that technologies are often inserted only as new educational practices (Rocha et al., 2013). The utilization of technologies as AR is not solely based on the mere introduction of said technologies, but rather on the collaborative creation of technological tools that aid in effective educational instruction.

On December 14, 2018, the document of the National Curricular Common Base for the High School in Brazil (BNCC, 2018) was approved. It is a normative document for the educational system, a mandatory reference for the elaboration of curricula and pedagogical proposals for basic official education. The document establishes guidelines for the construction of curricula, addressing the knowledge, skills, and

abilities that all students are expected to develop during basic schooling, including topics associated with CT. It is important to emphasize the importance of algorithms and their flowcharts, which can be introduced in Mathematics classes. Thus, the document points out that the area of Mathematics, in Primary Education, should focus on the understanding of concepts and procedures in their different fields and on the development of CT. In addition, the BNCC proposes that students use devices such as calculators and spreadsheets, since the beginning of Elementary School.

In this context, it is of uttermost importance to take advantage of the opportunity opened by the implementation of the normative document that restructures the Brazilian National Curricular Base that proposes the inclusion of the CT within the discipline of mathematics as one of the problem-solving skills. It is undoubtedly a viable possibility, but in order to materialize with results, it must overcome the same difficulties of the strategy of a specific discipline for this purpose: more curriculum hours, preparation of teachers, stimulating application activities, rigorous and constant evaluation, etc. It is intended to take advantage of this opportunity and to apply AR strategies in the development of CP.

To complement, the National Council of Education in Brazil (CNE) approved on February 17, 2022, the "Norms on Computing in Basic Education". This standardization places Computing, its foundations, and technologies, at the center of the Brazilian educational system.

AR allows the user (teacher or student) to position the camera where he wishes to allow an exploration of increased information from different angles. This information includes elements such as subtitles or texts in movements on the presentation screen. If the AR information is, an animal, this virtual animal can go to the background in history teaching, in which one can present the evolution through a touch.

The working approach followed in this doctoral project, to create a Learning Resource with AR technology, relies on the use of an Ontology (OntoCnE[1]) that describes in detail the concepts CT and Programming, and maps those concepts to different education levels, starting with the first year. A person just acquires a new way of thinking, or a new way of behaving, if he is trained with the appropriate learning resources. So a main investment to educate people in CT is in the choice/creation of those convenient resources. It is intended to investigate the impact of AR on the usefulness of such resources for the development of CT, an ability that Wing (2014) considers as fundamental as the ability to read, write, abstract, and more. Technologies developed by computer scientists should not simply be delivered to users without a survey of the real questions about the contribution, possibilities, and benefits of the system. The definition of the system's requirements must be built in collaboration with the user.

1.2 Objectives

As the context and motivation for the Ph.D. works is the challenging area of teaching/learning Computer Programming—an actually difficult and demanding activity, with plenty of failed moments—it is important to remember that Programming Computers to solve problems is much more than simply writing code

[1] OntoCnE means Ontology for Computing-at-School.

in a programming language; it is also necessary to analyze the problem, to plan a strategy to transform the input data into the desired solutions, and execute the program to test and optimize it. To train young students in those referred abilities that characterize the so called Computational Thinking, it is mandatory to choose carefully existing LR or to create with imagination effective new ones.

The Research Questions are:

- Can OntoCnE ontology help in choosing new and more engaging LR to train CT?
- What are the impacts of AR Learning Resources on CT?
- Can AR technology be also used to build tools to help students understand imperative programs?

The main objective of the Ph.D. project here proposed is to search for and improve motivation in training CT and help learn CP. In order to attain that objective, the following specific objectives must be achieved:

- Study broadly and deeply the area of AR in Education to characterize and classify the best possible those tools to understand well what is an AR-based resource, to know the systems that have been proposed and developed, what approaches have been used in their implementation, and so identify clearly what is solved and what deserves further research;
- Define an architecture (among the existing ones or creating a new one) that can always be adopted to build a AR-Based LR.
- Identify what components are stable and those that vary from a specific system to another one, in order to understand which information needs to be specified in each concrete case;
- Use the *OntoCnE* to guide the development of artifacts to training CT skill;
- Introduce a new methodology for the development of AR-based artifacts that train the CT;
- Validate with concrete case studies the approach proposed.
- Extend the previous approach and results so far attained to develop AR-based tools to aid in understating the behavior of imperative programs handling data structures.

1.3 Research Method

The methodology used in this research will be *Design-based Research* (DBR) proposed by Collins (1992). This methodology focuses on three iterative phases: (1) analysis and exploration, (2) design and construction, and (3) evaluation and reflection. Design-based research (DBR) evolved near the beginning of the 21st century and was heralded as a practical research methodology that could effectively bridge the chasm between research and practice in formal education. DBR also requires extensive planning, a toolkit of expansive research methodologies, and attention to practical and theoretical considerations. Mckenney

and Reeves (2013) created a model that well illustrates the interactions of the methodology, as depicted in Figure 1.2. After a decade of using the methodology, Anderson and Shattuck (2012) identified many publications and popular interventions used, demonstrating the consolidation of the DBR research methodology.

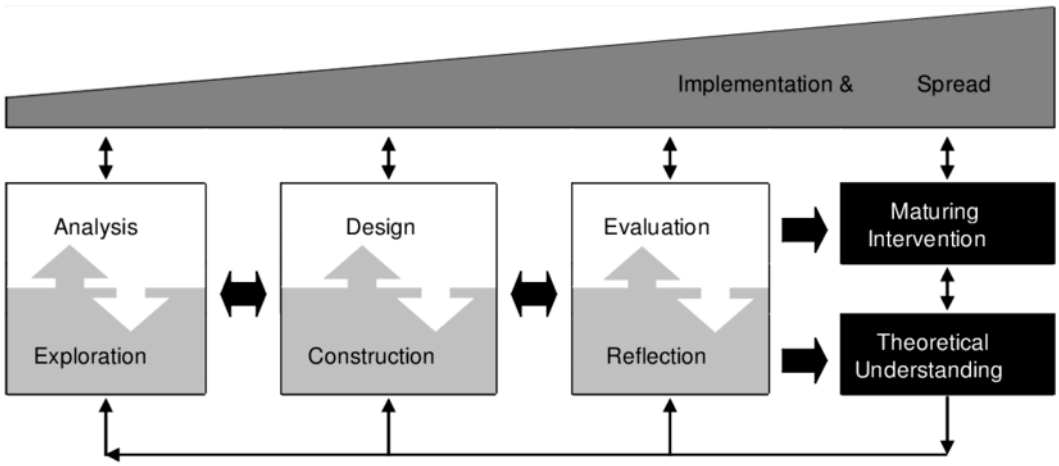


Figure 1.2: Design-based research (DBR) by Mckenney and Reeves (2013).

DBR offers an approach to generating practical, theoretical, and academic contributions to education research, resulting in innovative and creative solutions to complex problems. The main objective of this approach is to generate new theories and frameworks for conceptualizing learning, instruction, design processes, and educational improvements. An important characteristic to achieve research objectives out our investigation.

The core of this methodology consists of a sequence of activities that produces an interaction. With the artifact created it is possible for the researcher to better understand the problem and have a clearer view to reassess the problem and thus improve the quality of the design process in a construction loop until developing a final artifact to solve complex and relevant field problems.

So for developing this artifact using the Design-based Research methodology, Mckenney and Reeves (2013) state that there are six guidelines to follow:

- Exploration of the problem domain, and study the principles, theories, and related work;
- Analysis and exploration;
- Design and Development (construction of the artifact).
- Evaluation and reflection based on collaboration with users in the real world;
- Interactive process;
- Communication (academic publications).

First Phase: This phase was used for the basic bibliographic survey and the construction of a review of the state of the art. This study covers the concepts necessary to successfully develop the project. In the case of the present doctoral work, three main areas shall be studied:

- Haptic Interface in the AR System for the creation of educational tools to improve Computational Thinking;
- Plugged or unplugged Learning Resources to help on Computational Thinking and Computer Programming;
- AR-based Learning Resources to help on Computational Thinking and Computer Programming.

Second Phase: At this stage, an AR System architecture with natural and coherent interaction of AR-based LR shall be sketched and proposed. Third Phase: It is intended to carry out the implementation of the architecture. Fourth phase: This phase will be devoted to testing the results of the implementation carried out in the third phase. For this, it is necessary to choose a case study.

The last two phases are intended to promote, by publishing papers in international conferences, innovative solutions to the challenges of education by presenting a strategy for creating learning artifacts based on Augmented Reality that train Computational Thinking.

1.4 Research Hypothesis

Learning Resources based on AR helps understand one problem and solve it supported by concepts and practices relevant also for computer programming; exploring those resources will encompass the student's skills such as systematizing, representing, analyzing, and solving problems.

1.5 Document Organization

Besides the Introduction and Conclusion, this document is organized in three parts: Literature Review; Development of AR-based Learning Resources; and Generalization of AR-based Learning Resources creation. Part I is structured as follows. Chapter 2 opens the discussion about a relevant area, the use of Computers as tools to support education; In that context, the concept of Augmented Reality as well as methods, technologies associated, and applications to different domains are also revised in Chapter 2. Chapter 3 introduces the notions of Computational Thinking and Learning Resources that lead a substantial part of this doctoral work; In particular, the use of Augmented Reality to improve Learning Resources is discussed.

Part II includes 6 chapters. Chapters 4 to 7 present, in conceptual and technological detail, different software packages developed to provide Learning Resources aimed at training Computational Thinking, focusing on young students. Different approaches and techniques are discussed. Chapter 8 introduces a major contribution of this doctoral project: an AR-based tool to help programmers in visualization data

structures. Chapter 9 is about the experiments designed and conducted to assess the different Learning Resources developed.

Part III contains just Chapter 10 devoted to one of the main contributions of this Doctoral project: The proposal of a strategy for the development of AR-based Learning Resources to help the education in Computational Thinking and in Computer Programming.

A summary of the overall work done and its presentation in this document, conclusions, and discussion of possible directions for future work are included in Chapter 11, which closes the dissertation.

Part I

Literature Revision

Chapter 2

Augmented Reality in Education

Humanity produces material and non-material work, the latter refers to human production that deals with the production of knowledge, ideas, values, symbols, attitudes, and skills. Education is situated in the concept of non-material work. But education is not reduced to teaching, teaching is education and thus also becomes an educational phenomenon. In this context, Saviani (Saviani, 1984) argues that educational work is the act of producing, directly and intentionally, in each unique individual. Humanity, on the other hand, is historically and collectively produced by all men. Thus, the objective of education is focused on identifying the cultural elements to be assimilated and what are the most appropriate ways to achieve these objectives. That is why the author emphasizes the organization of how the individual will develop his humanity. Thus, it is said that the school is an institution whose role is to socialize systematized knowledge. The activities of basic schools must be organized in which the school exists to provide the acquisition of instruments that allow access to elaborated knowledge or the development of humanity. Bearing in mind that the curriculum is the set of activities carried out at school, a good curriculum provides for the development of the individual and society. The author also states that having the curriculum as a guiding guide for the development of knowledge, the conditions for its transmission and assimilation must be found, dosing, and sequencing so that the student is successful in his journey. In the practice of activities, it is necessary to master the contents so that later there is freedom of creation. For example, to write a program, the programmer knows the commands of a programming language, but it differs from creating an efficient system. To program it is necessary to constantly repeat the same acts until you become familiar with them. As well as the skills inherent to Computational Thinking. To acquire *habitus*, it is necessary for people to create an irreversible situation where insistence and persistence are required. In short, a programmer can create simple programming language codes, but only when the act of programming is mastered does creative freedom develop. Therefore, there are statements that Learning Resources that use AR technology can

develop greater motivation and impact through the construction of deliberate and systematic activities. It is concluded that society needs other modalities of pedagogical practices aimed at Human development. The author Dewey (1938) innovates using the teaching learning model focused on the student as a subject of its own. The author emphasizes that learning must start from the problematization of the student's previous and daily knowledge. The author also highlights those manual activities, which contain problems to be solved, give students greater motivation in addition to developing the spirit of cooperation. The educator can discover the student's interests in everyday activities, these interests can be stimulated with activities that train Computational Thinking. The use of technology such as Augmented Reality allows us to create new analogies to visualize complex concepts. Related teaching activities that explore the development of PC-related skills, gamification, real-time interaction, with or without equipment, impact the way teaching takes place.

To show the importance of making adequate teaching means, the author Lajonquière (1997) presents how Jean Piaget boosted Cognitive Theory. Piaget demonstrates that "the human cognitive capacity is born and develops, it does not come ready-made". Thus, the author states that knowledge originates from the "subject-object"interaction. Piaget had as his disciple Seymour Papert. Thus Papert consolidated the term constructionism as the constructivism approach that allows the student to build his own knowledge through some tool, such as the computer, for example. The author was the creator of the LOGO programming language in 1967 for children.

2.1 Augmented Reality

Virtual Reality and Augmented Reality make up the Computerized Hybrid Worlds. These technologies fascinate and are absorbed naturally by society in the most varied ways and integrate into our everyday life taking over the new technologies to perform human tasks. The classification of Virtual Worlds to which AR is part can be seen in Figure 2.1 a unifying view of a real environment compared to a virtual environment broadly defined as Mixed Reality. Unlike VR where the user is fully immersed in the environment and vi-

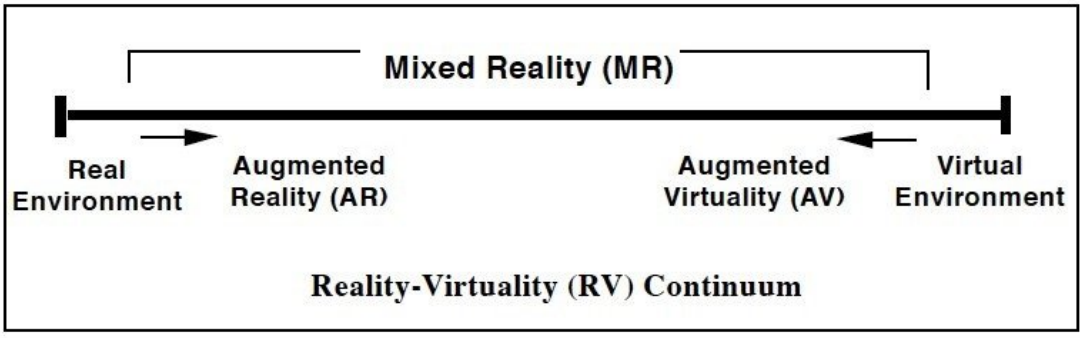


Figure 2.1: The reality-virtuality continuum (Milgram et al., 1995).

sual sense is controlled by the system, AR increases information in the real world, the user maintains a sense of presence in the real world and requires mechanisms to combine the real world with the virtual

one (shown in Figure 2.2). AR can be defined by enriching the real environment with virtual information using some technological device. These systems work in real-time and this enrichment can be with texts, images, and/or virtual objects generated by a computer, aligning the real objects and virtual information with each other (Azuma, 1997). Azuma states that to be an AR, it is essential to fulfill three final conditions: Combine real and virtual, interactive in real time and registered in 3-D.



Figure 2.2: AR Example with virtual object superimposed in the real world.

The evolution of AR is represented in Figure 2.3 (Qiao et al., 2019). AR essentially explores vision and hearing but the enrichment of information applies to all senses, including tact strength, and smell as Azuma already presented in his work (Azuma et al., 2001). AR systems can be classified according to the type used by the viewers or to the type that viewer used, involving optical vision or video vision, giving rise to four types of systems.

Nowadays Augmented Reality Community Group was created by the World Wide Web Consortium (W3C). The group is an open forum for collaborative discussions about the intersection of Augmented Reality standardization enfolding the changes brought by HTML5 and other related standards. Figure 2.4 an example of AR will be shown. It can be seen that before the systems were built with the ARToolkit library. But the great popularization of AR came after the launch of the Pokemon Go® game that reached more than 500 million downloads, thus popularizing the use of Augmented Reality on mobile devices. There are different types of AR in relation to the way they use increased information, they are Marker-based, like as in Figure 2.4, and Location-Based. Marker-based is based on image recognition. The system uses a camera to detect patterns or markers AR like a QR-code or image. After a pattern is recognized, the system overlays augmented information on this marker and the orientation of the virtual object depends on the position of the marker. The systems do not use markers and are Location-based. These types do not need a marker, they are markerless, instead, they use GPS and other position sensors of mobile devices to establish their

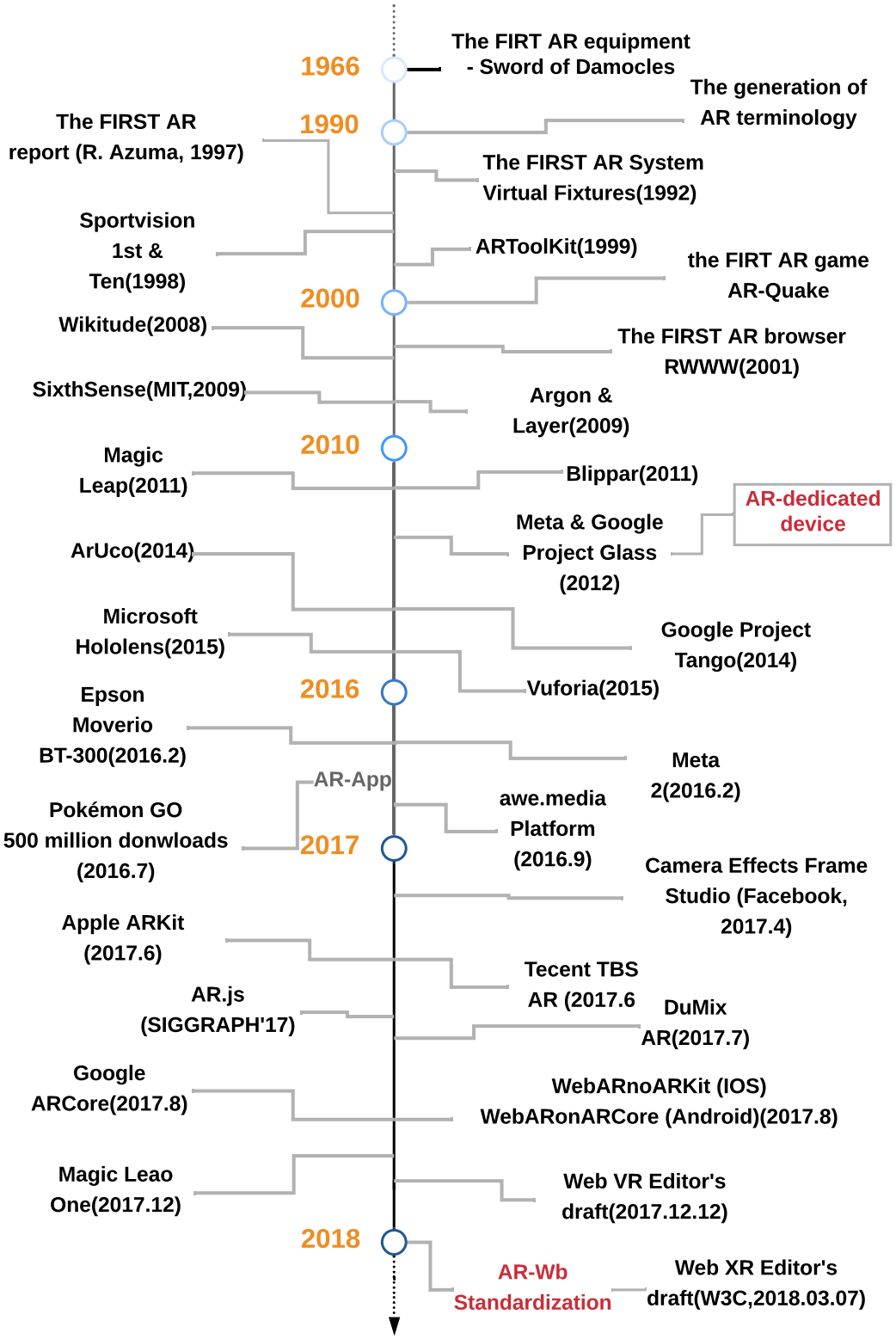


Figure 2.3: Historical evolution of AR adapted Qiao et al. (2019)

location and create AR objects.

The work of Munoz-Montoya et al. (2019) uses the Simultaneous Location and Mapping (SLAM) technique, this technique allows the devices to map an environment and create a 3D point cloud and thus, like this 3D map, the system can position a virtual object in a given while a user moves around the room seen



Figure 2.4: AR Example marker

in the Figure 2.5. In this work, the author presents an AR game based on SLAM to evaluate short-term spatial memory.

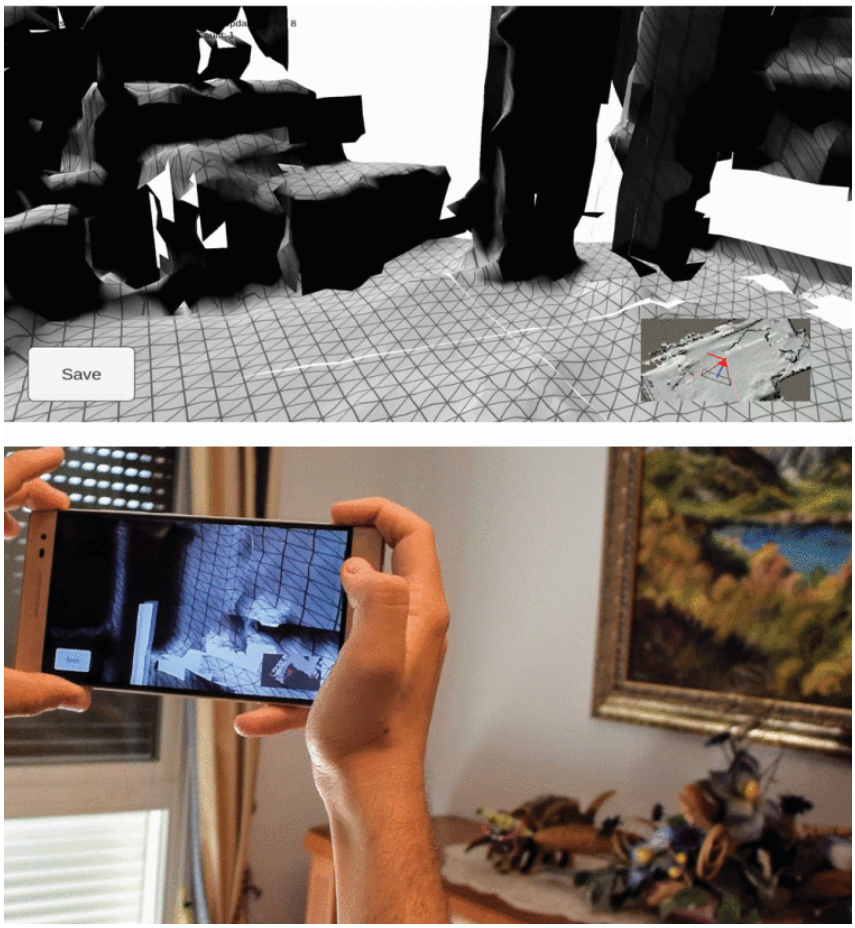


Figure 2.5: Technique of SLAM for AR

Regarding the type of visualization on the devices, it is classified into:

- Mounted on the head on direct vision device (shown in Figure 2.6);
- Direct video vision system or handheld (show in Figure 2.7 and 2.8);
- Monitor based video monitoring system (Figure 2.9);

- Projection optical vision system.

The direct optical vision system uses glasses or helmets with displays that allow the direct reception of the real image, while also enabling the projection of virtual images properly adjusted with the real scene. A common way to achieve this feature is to use a tinted lens that allows direct viewing and reflects the projection of computer-generated images directly into the user's eyes.

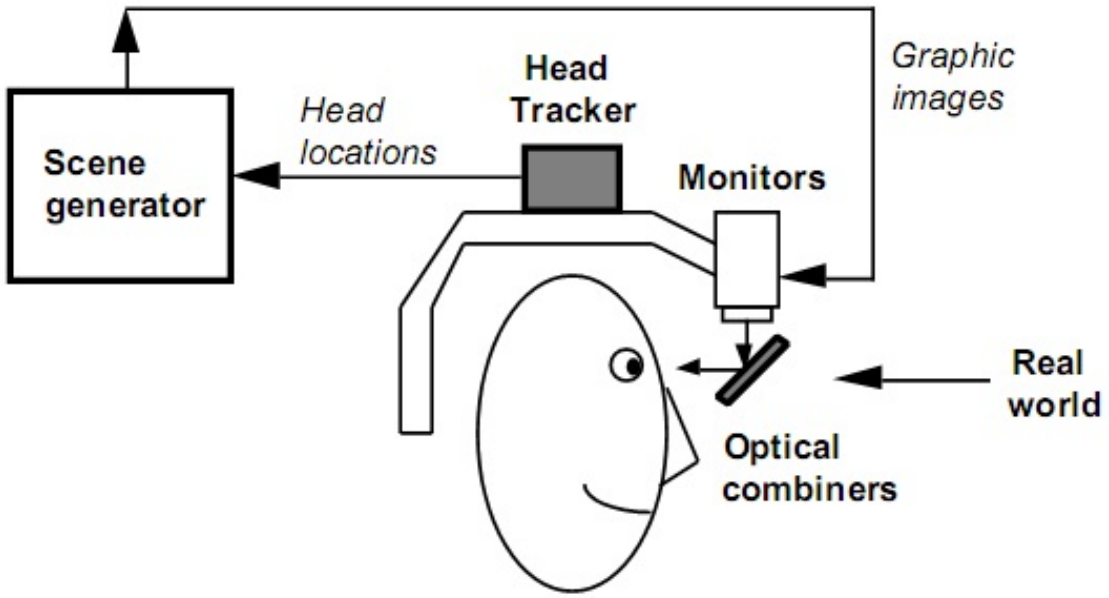


Figure 2.6: Diagram of Azuma (1997) of the system of direct optical vision.

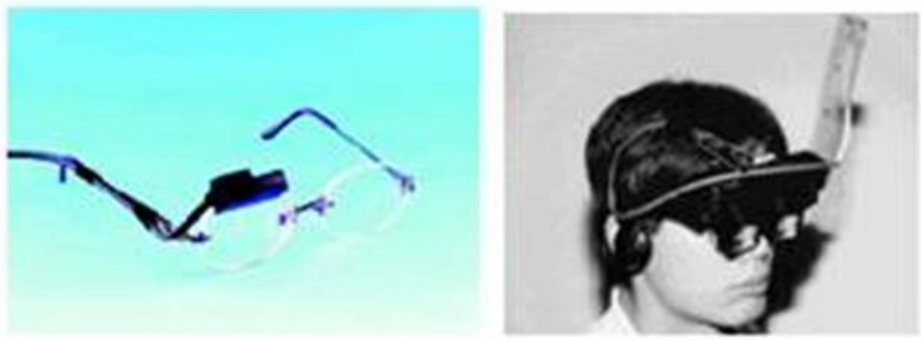


Figure 2.7: Example of a direct vision device.

The direct video vision system uses helmets with coupled video micro-cameras. The actual scene captured by the camera is mixed with computer-generated virtual elements and presented directly into the user's eyes through small monitors mounted on the helmet. Figure 2.8 shows the diagram and presents a direct-video-view device. The monitor-based video vision system uses a *webcam* to capture the actual scene. Once captured, the actual scene is mixed with computer-generated virtual objects and displayed on the

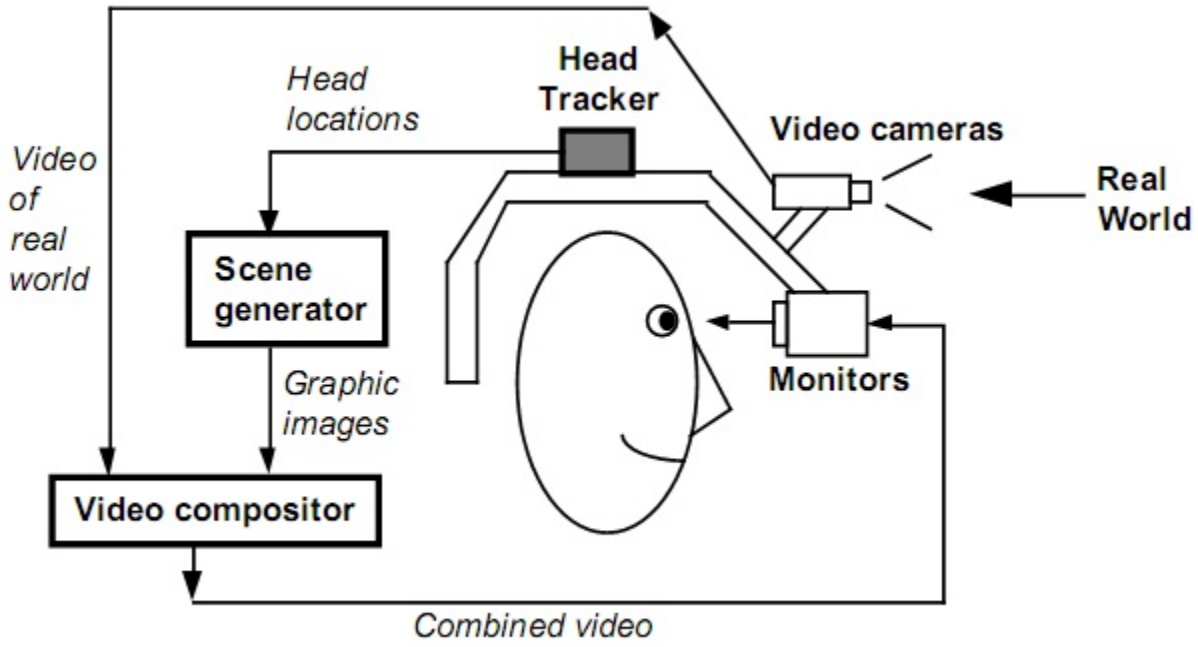


Figure 2.8: Diagram of Azuma (1997) of the direct video system.

monitor. The view of the user is usually fixed and depends on the positioning of the *webcam*. Figure 2.9 shows the diagram and the equipment used in this case. As mentioned earlier, there are systems that

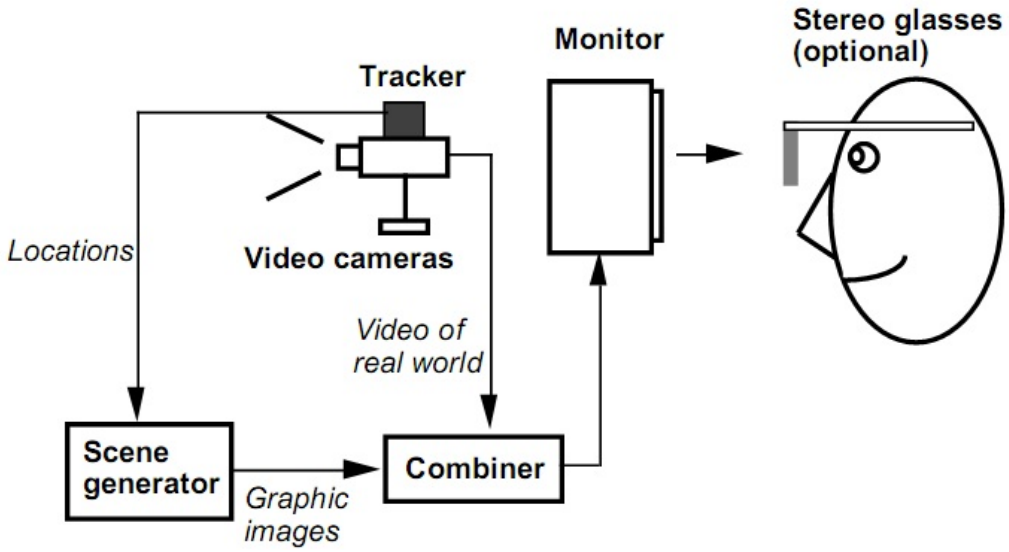


Figure 2.9: Diagram of Azuma (1997) Monitor based video monitoring system.

do not use markers and are location-based, instead using GPS and other mobile device position sensors to establish your location and create AR objects. A typical AR process in a mobile device is shown in Figure 2.10 of the camera and other types of sensors are used to capture information in real-time and continuously.

AR supports pedagogical approaches through Constructivist learning by enabling educational experiments

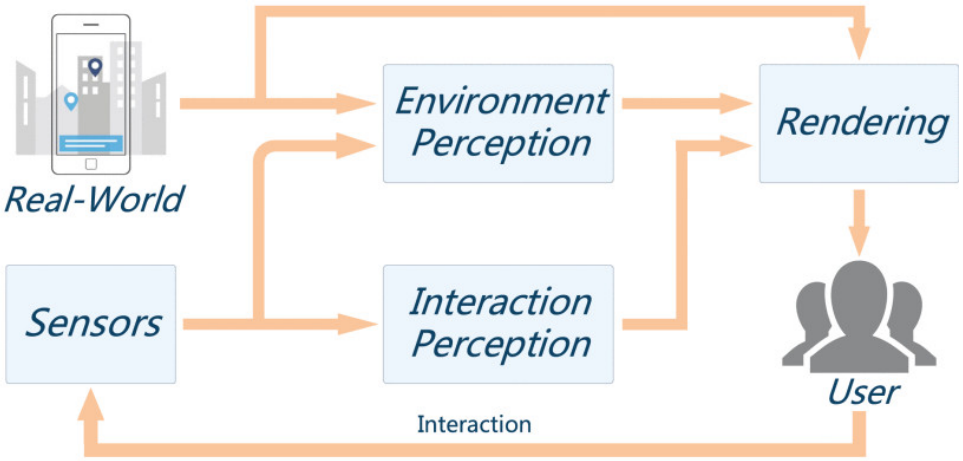


Figure 2.10: A typical AR process using Mobile Devices

that complement the activities of the real classroom. Thus it is possible to explore AR as a technology that provides a wide range of skills such as problem-solving, abstraction, and creative manipulation of the computer as a user, not only as a mere technology operator but as a computationally literate individual. Therefore, AR in education can be applied in the training of students' abilities, encouraging learning, based on discoveries, which can be made through exercises of a simple virtual representation of the information through books in AR or developing challenges through games. AR can be used to provide a rich contextual learning environment, appeal to Constructivist notions of education, provide opportunities for multiple learning styles and engage the learner in ways that have been made possible and there will not be any real consequences if any mistake is made during skill training. The ability to formulate algorithms for computers is how to construct instructions for a computer to solve/repeat processes. This action is related not only to solving simple or complex tasks but also to learning to build algorithms has a great cognitive load.

2.2 The Use of AR in Education and Training

The important review of Bacca et al. (2014), presents a focus on the use, advantages, limitations, effects, challenges, and characteristics of the application of AR in Education evaluating 32 studies published between 2003 and 2013 in indexed journals. In order to present its results, it tries to answer in its review the main uses, purposes, advantages, limitations, effectiveness, and possibilities of AR in educational environments. The author also tries to verify if the user was included in the process of collaborative development in the applications studied and what the evaluation methods considered for applications of AR in educational scenarios. The main research results for AR and Education are related to identifying the benefits of the educational sciences through the application of AR where the activities are applied to situations that can not be seen in the real world. An important point identified by the author by quoting Furió et al. (2013) is that AR is effective in teaching abstract and complex concepts because students can immediately see the virtual elements. The results also show that there is little research exploring the area of health and well-being and little research in the provision of services such as travels, security services, transportation,

teaching and training in agriculture, veterinary, forest, etc. The author identifies in review the application in higher education levels and the possibility of exploring vocational education, stating that it is necessary to prepare the students for work activities, but no work has been found applied to early childhood education; This important point to highlight because at this stage children understanding and abstraction can be stimulated and there are no "barriers"to thinking as in adults. Different applications using AR are then perceived which propose to explain a specific topic and exposure of increased information, these systems promote supplementary material using AR. The author's studies affirm that there are gains in learning and an improvement in students' motivation using AR. Thus Bacca et al. (2014) presents a list of advantages that have been reported of the use of AR in education in the works reviewed by it. They are: learning gains, improved motivation, facilitated interaction, collaboration, low cost, increased experience, real-time information, situated learning, student-centered application, increased student attention, enjoyment in use, development exploration, increased ability of innovation, encourages the creation of positive attitudes, awareness raising, Anticipation, presentation of technological innovation, Authenticity. The limitations reported in AR systems in education are related to difficulties in maintaining overlapping information in the system because the systems for tracking and positioning the increased information often fail and frustrate students. Another limitation is that students are distracted by the technology itself and do not focus on the content presented. The teacher's independence in creating content using AR has as a future work of research as there is no need for specific knowledge or skills to use the system, an important point to be addressed with user-centered development to create good usability and easy creation of routines

Three types of applications in AR education are explored according to the type of positioning of the increased information: they are based on printed markers, with no markers, and the positioning of the augmented information is based on location. This last exploration with GPS information and SLAM techniques.

The reviews by Lee (2012) of the use of AR in education and training, the use of technological innovations in education has great value and provides greater engagement and motivation in the medium that applies, but AR always finds difficulty in it and there are still questions to be answered about the needs of the definitions of academic applications. Thus Lee (2012) states that many professionals and researchers are developing pragmatic theories and applications in the adoption of the System of AR for Teaching (SMART) like the application Freitas and Campos (2008), conducting various experiments with middle school students and indicating that the technologies employed improve the motivation among students having a positive impact on teaching experiences. Like in Figure 2.11.

AR can be used in the exploration of contents that are difficult to understand and absorb for students as difficult and mechanical theories as the work quoted in Liarokapis et al. (2004), develops a virtual model of the operation of an engine; application to understand contents with astronomy (Shelton and Hedley, 2002), (Johnson et al., 2010), thus showing the ability of students' abstraction using technologies; in chemistry, there is Fjeld and Voegtli (2002), they presented as is an atom and the anatomical structure of the human body presented using AR technology which is ordinarily made in books or in anatomy labs.



Figure 2.11: Some 3D models in project of Lee (2012)

See in Figure 2.12.

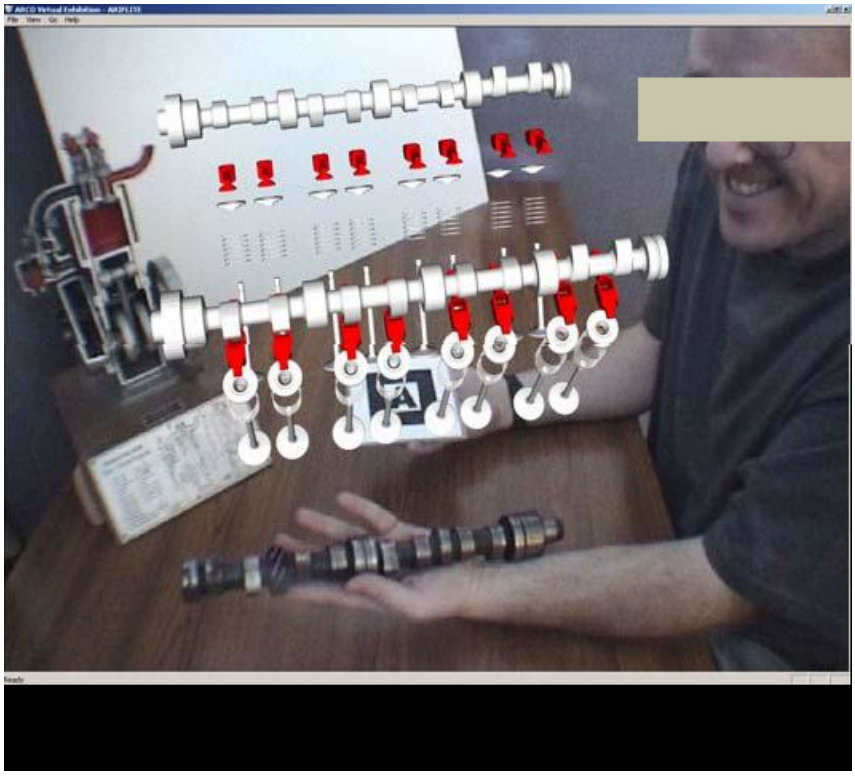


Figure 2.12: Work of Liarokapis using AR

Chang et al. (2010) developed a system for teaching mathematics and geometry with constructions of three-dimensional models, different from the works presented. The author here made its collaborative application, allowing multi-users in a collaborative virtual space using HMD head-mounted displays). The

works of Duarte et al. (2005) and Chae and Ko (2008) applied to physics teaching demonstrate that using such techniques makes teaching more interesting than traditional learning methods, improving and increasing the learning potential. Information visualization techniques through 3D object rendering can turn books into "magic"books for children (Billinghurst et al., 2001), (Billinghurst, 2012), which presented new horizons for teaching at the beginning of the 21st century. Thus in this review, Lee (2012) predicted future applications of AR would provide greater interaction, providing a productive, pleasurable, and interactive environment than traditional forms of teaching, but not as a unique form of teaching but as an auxiliary technology. It is important to emphasize that systems should be focused on simplicity and can be based on the constructivist approach to teaching, where the student assumes the role of knowledge construction. Errors can be committed without the same effect as when they happen in real environments and training, the actions in those virtual systems can be repeated, frozen, or suspended as many times as necessary other than actions in the real world. Education systems can also be applied in industrial training such as simulations of hazardous environments such as power stations, industrial inspections, laboratory simulations, and others, without the risk of accidents.

2.3 Application of AR in Science Learning

With the needs society has for professionals trained in the areas of STEAM (science, technology, engineering, and mathematics), the focus should not be only on the environments of educational physical places but also consider informal education. In this work, Goff et al. (2018) made a review 2018 investigate the use of systems of informal learning with AR in science education. The author focuses on STEAM in different mobile devices. In this review, Goff et al. (2018) attempts to answer some questions of which focus are mostly addressed in developed systems, which are the most common designs, which are the main technological devices, and which results have been most reported in the surveys. Results were limited to that focused on research-based informal learning sites related to the STEAM fields, the author found 17 papers for this review using your settings. The author has identified two types of categories of AR systems, those based on images (use markers) and those based on location (no printed markers), the latter using object recognition or localization to position the AR information. Systems that do not use printed markers use GPS or Wi-Fi information to position virtual objects in the system environment. The theme of the most published studies of the use of AR in education between 2011 and 2016 by Chen was in the area of science education prevailing the forecast realized in the revision of Koutromanos et al. (2015), preference for science teaching is related to problem-solving research, the main feature of science. Chen's most recent work in 2017 focused on the use of mobile devices as a vehicle for AR programming (Chen et al., 2017) showing the good opportunity of using mobile devices as a promising method of introduction the AR. Both works report the benefits of AR in formal settings.

The AR can help guide the learning process based on the five principles of the cognitive theory of multimedia learning proposed by Mayer and Mayer (2005), they are: multimedia principle, spatial contiguity, temporal contiguity, modality principle, and signaling principle. Thus, many AR applications are developed

based on theories of situated learning and constructivism, together providing those developing applications for learning environments with a solid background for the design of future software. The theory most used in the works researched by the author was the theory of constructivism, but thinking in the interface and design, the author affirms that in the future design guidelines should take into account each of the theories educational collaboratively as practitioners' plan and discuss the development of AR technology. The author found that the reported jobs used smartphones/tablets (41%), the rest used a fixed computer or an HMD (59%), the difference in the types of devices used is associated with the price, using mobile devices, there is a reduction in cost-effectiveness and versatility. The popularization of mobile devices creates the opportunity for social inclusion and collaboration, including people from low-income communities, providing active engagement in a process of teaching activity.

Lai et al. (2019) work with AR multimedia textbook (ARMTB) and the experimental results of showed an approach based on the contiguity principle of multimedia learning promoted the students' learning achievements and motivations and their perceptions of extraneous cognitive load were significantly decreased during the learning activity. See a example of the work of the app Augmented if Figure 2.13.



Figure 2.13: App AR-based science learning activity of Lai et al. (2019).

The author affirms the ARMTB approach can effectively improve "Attention," "Relevance," "Confidence," and "Satisfaction", and then suggests the future approach through multiplex learning. The work of Sáez-López et al. (2019) analyzes 93 primary school students as they worked on content in mathematics and sciences with visual block programming and robotics, using the teaching of algorithms with visual programming in blocks and robotics promoting substantially their understanding of the elements of logic and mathematics, demonstrating improved understanding of mathematical concepts and in the acquisition of computational concepts.

Chapter 3

Plugged and Unplugged Learning Resources

This chapter is devoted to introduce two main concepts of uttermost importance for the thesis discussed in this dissertation: Learning Resources (LR, for short); and Computational Thinking (abbreviated to CT). Along the chapter, it will also be presented OntoCnE, an ontology that will be used to describe CT and interconnect it with Computer Programming (CP) from author Araújo et al. (2023). In the last section, it will be shown how AR technologies, introduced in the previous chapter, can be used to improve LR to train CT.

3.1 Learning Resources

Learning Resource (LR) is a tool that helps educators in teaching and students in learning. LR are hard or soft devices that allow students to train previous knowledge or acquire new knowledge, stimulating their ability to comprehend, organize, and synthesize educational content in a specific domain (Bušljeta, 2013). The next list shows different family artifacts that illustrate the concept of LR.

- Activity books
- Apps
- Movies
- Educational games
- Educator workshops
- Flashcards
- Graphic novels
- Labs

- Magazines & periodicals
- Manipulatives (blocks, beads, etc.)
- Maps & atlases
- Models
- Non-fiction books
- Online courses
- Podcasts
- Posters
- Reference books
- Software
- Study guides
- Teacher guides
- Televisions shows
- Textbooks (print and digital)
- Websites-Webcasts
- Workbooks
- Worksheets

It is necessary to resort to LRs to train the CT; so LRs will play a very important role in this process. However, it is crucial to have adequate resources to transmit the different skills involved in CT. The richer the resources, the better students will shape their minds, learning the desired competencies.

The LRs that were used are of two types:*virtual* (need electronic devices) and *unplugged* (do not need any kind of electronic devices). Now for use in the classroom, teachers can teach the fundamentals of computer science with unplugged lessons. Use some lessons as a stand-alone course or as complementary lessons for any computer science course. There are *Code.org* [1], for example, with many types of unplugged activities, they help to complement Computer Science activities and related concepts. There are activities directly linked to the logic of programming, involving the manipulation of concepts like loops, sequences, events, conditionals, and binary numbers. Other activities are directly linked to the training of CT (decomposition, pattern matching, abstraction, and algorithms).

For instance, the activity *Building Monsters*, depicted in Figure 3.1, is a pairwise unplugged activity to be proposed in the classroom that involves decomposition and algorithmic reasoning and requires pattern recognition, abstraction, and synthesis capabilities. In short, a student analyzes the catalog of pieces to build monsters, and the set of illustrative monsters; then he builds his own monster, after recognizing which are the parts that make up a monster. When he finishes this phase, he writes an algorithm so that his colleague can execute step by step aiming at producing the same monster. In the third step, the students must discuss the drawing obtained and assess the algorithm result; in case of fail, they have to understand whether the first student wrote a wrong algorithm or the second executed it incorrectly. At the end, students can alternate algorithms with another group and test to see each other's results (Debug).

Another example of a *unplugged* resource is the Storytelling Data Kit. In this resource the physical device is a set of dice, marked on each side with small images of different kinds of objects (trees, flowers, fields, houses, animals, persons, etc.); after shuffling and launching the dice children are invited to create a

[1] *https://code.org/curriculum/unplugged*

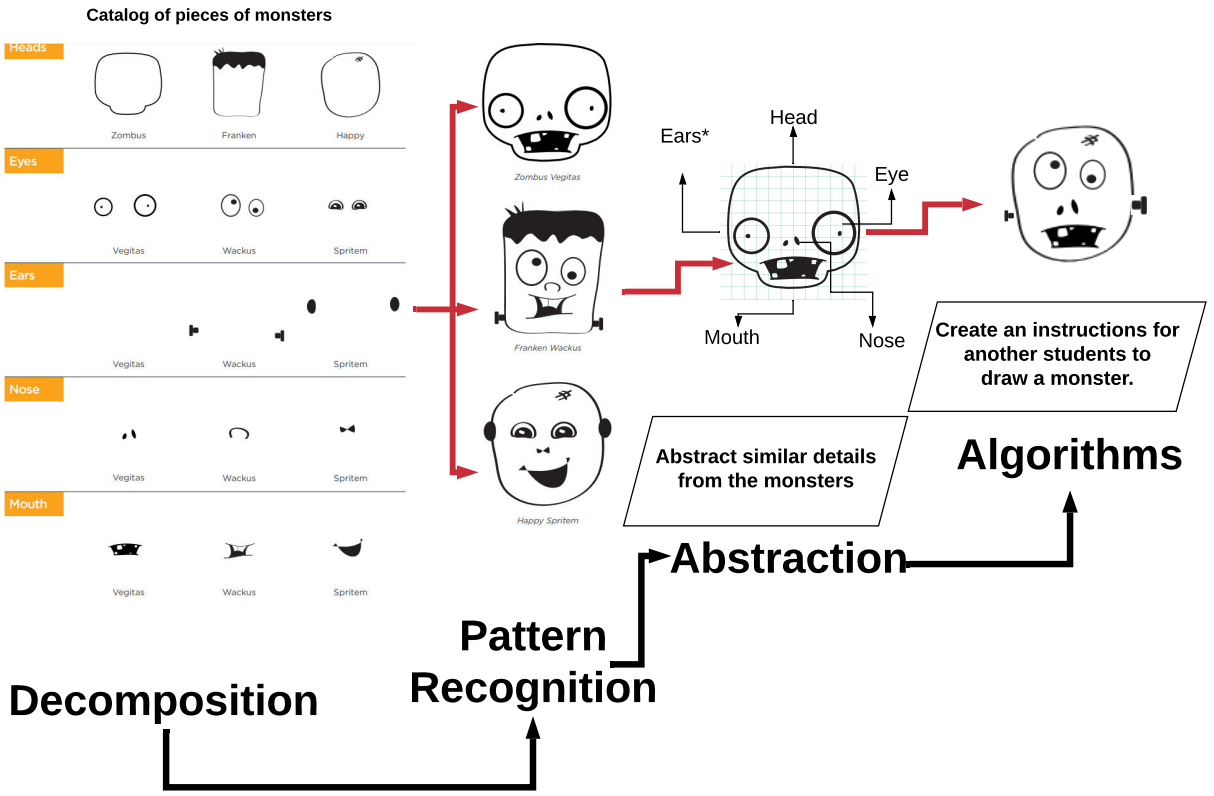


Figure 3.1: *Building Monsters* to train CT, a classroom game

sequence with them and tell stories that contain the objects assigned to the top side. This game allows to foster creativity, confidence, and imagination.

The CODE robot in conjunction with a *mathematical carpet* is an example of a *virtual* resource, and at the same time *unplugged*. Students can build the *carpet* with 15x15 grids and fill them with numbers. After the setup of the game (carpet and mathematical questions prepared), the student is invited to pickup a question(an expression involving the normal algebraic operations), from the table and after giving the answer (a number), has to program the robot to walk through the carpet to go from the student's home to the expected number result. This device allows students to apply and develop mathematical concepts, programming, abstraction, and sequence.

For plugged activities, *Scrath* (Resnick et al., 2009) is one of the most common LR, used to initiate the training of CT. Radu and MacIntyre (2009) have extended the Scratch platform with AR technology, creating a nice environment (shown in Figure 3.2) to introduce children to programming activities.

Another example of a *virtual* resource is Python-Tutor(see in Figure3.3), which aims to animate programs written in Python. Online Python Tutor is free and open source software, available at pythontutor.com.

This resource is suitable for those who are writing the first steps in Python programming. Initially, the students should write their program and then introduce the program in Python Tutor to see immediately the animation of the data structures and control flow implicit in their program.



Figure 3.2: AR Scratch environment

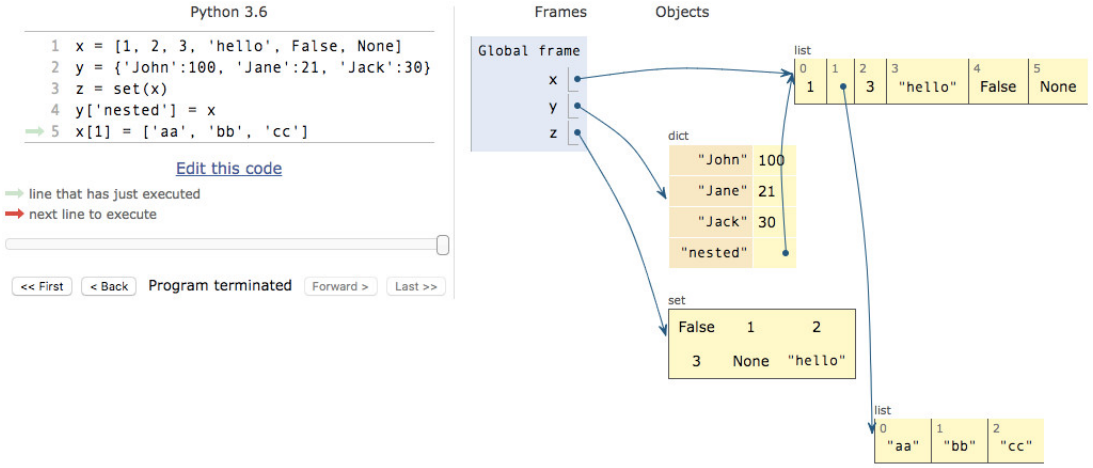


Figure 3.3: Python tutor environment

Lighbot is a programming puzzle Lightbot, created by Yaroslavski (2014) for kids that involves programming concepts in its mechanics. The goal of Lightbot is to, guide a robot to light up all the blue tiles on different levels. To play, the student needs to write an appropriate sequence of instructions for the character to execute in order to perform the desired movement, as seen in Figure 3.4.

Thus it is possible for students to understand the general levels of programming and how to think algorithmically to arrive at a solution understanding the concepts necessary for CT. The *Lightbot* addresses two concepts: programming practices in the construction of the solution of the problem; and sequence of steps in the execution of the program (Flow of control). To achieve success, content producers must work to ensure that every teacher and student has access to a range of high-quality instructional materials. Engaging, effective, and diverse educational resources that promote learning, improve skills, and accelerate student achievement are central to training CP.

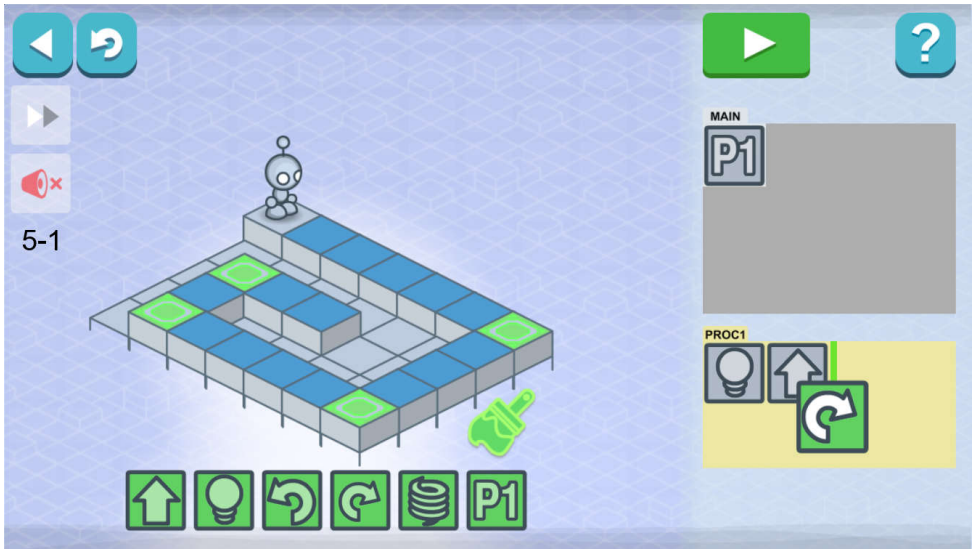


Figure 3.4: Lightbot puzzle game coding

3.2 Computational Thinking

According to Wing (2014), the most important and high-level thinking process is the process of abstraction, which is being used in the definition of patterns, generalizing from specific instances and parametrization. With adequate resources, it is possible to work with the identification of common characteristics between the problems and their solutions. Araujo (2022) details more information about the impact of Computational Thinking on Computer Programming. It is also possible to identify patterns among the sub-problems that are abstracted, finding an efficient solution to the problems encountered. It is possible to work with resources that help breakdown processes into smaller parts for easier resolution. Thus it is possible to prepare the thought so that it arrives at the moment of creation of the Algorithms in the strategy or clear instructions for the solution of the problem. CT completes the set of stages of education where the focus is the ability of systematizing, representing, analyzing and solving problems, describing and modeling the world and its complex processes. The development of thought, itself is impacted by technology and this theme has been in studies for more than 20 years when in 2000 it was defined as digital literacy (DiSessa, 2001), which consists in differentiating the simple user of a computer from the user who knows how to explore technology to efficiently solve problems.

Section 3.3 discussed related works in the field of Education using an AR approach. Computational Thinking is the mental process of formulating concepts with enough clarity, and in a systematic enough way, that one can tell a computer how to do them Wing (2010). Figure 3.5 shows the concepts related to CT and how they are related.

Each complex problem should be broken down into several small parts and steps (decomposition); only the relevant details are focused on (abstraction), past problem-solving experiences should be remembered and applied (pattern recognition...), and then come up with a plan of action step by step (algorithms). Thus, it is necessary to develop new learning activities that can be enriched with technologies such as AR. In the next section will be shown OntoCNE, a formal language for describing CT at school.

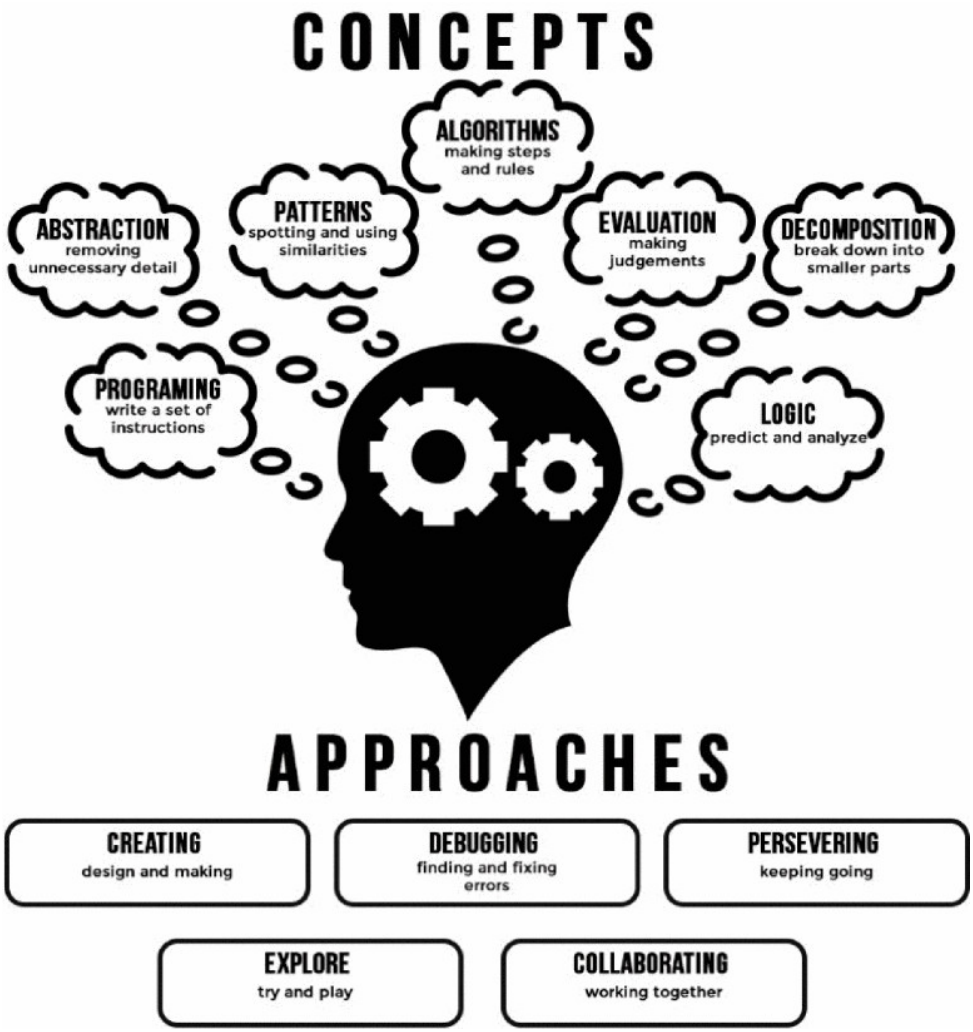


Figure 3.5: Concepts and approaches of CT(adapted from: Computing at School)

3.3 Describing CT with an Ontology

Ontology is a term derivative from philosophy, seen as the development of artifacts formulated for a specific purpose and with objective criteria. To Gruber (1993) *"Ontology is an explicit specification of a conceptualization"* or is the statement of a logical theory.

For Guarino (1997), ontology is *"an artifact of engineering, consisting of intentional vocabulary related to a certain reality, together with explicit assumptions in the form of first-order logic, representing concepts and relationships between concepts"*. An Ontology, in Computer Science, represents a set of concepts within a domain and the relationships between them. An ontology is used as a specification of a representational vocabulary for a shared domain of discourse—definitions of classes, relations, functions, and other objects.

To plan teaching activities to train this kind of thinking, to devise educational resources for this training, etc. A formal definition of the domain to be studied is required. In this sense, it was chosen to use an ontology to specify the CT domain. The ontology created is called *OntoCnE* [2]. It describes the domain of CT, more specifically which concepts must be taught, and what material is needed to train it in the different years

[2] '*Ontologia sobre Computação na Escola*' a Portuguese term that means '*Ontology for School Computing*'

of schooling.

After using *OntoCnE*, the concepts to be taught in each academic year were selected and new concepts were added to the ontology. By linking the new concepts added to the existing ones, is intended to create new relationships and also augment the concepts necessary to teach. The principles adopted to build OntoCnE, and its first version were discussed in (Araújo et al., 2019). After the construction of the first layer of the ontology(identifying the main concepts that describe the topics TC and CP), the concepts that would be taught in each academic year were selected and new concepts were added to the ontology, creating OntoCnE second layer.

This ontology will allow the classification of the resources that will be used to train a certain concept at a given level of education. The research carried on by (Azevedo et al., 2019) describes Micas, as a tool that allows to store the resources and classify according to school. Listing 3.1 exhibits an OntoCnE fragment, written in OntoDL language, that shows concepts taught in the 1st year of *OntoCnE*.

Listing 3.1: Concepts taught in the 1st year (fragment)

```
1       Triplos{
2       ano1 =[
3           desenvolve=> PensamentoComputacional,
4           desenvolve=> RaciocinioLogico,
5           desenvolve=> Abstraccao,
6           apresenta=> Problema,
7           introduz=> Algoritmo,
8           introduz=> Instrucao,
9           introduz=> Programa,
10          introduz=> DispositivoDigital,
11          introduz=> LingGrafica,
12          usa=> Computador,
13          usa=> Robot ];
14      }
```

With this Ontology, is possible to describe the way to build adequate Resources. The author states that teaching CT will bring new challenges to education, especially in the early years. There are already models for teaching physics and mathematics and the author presents a model for teaching CT.

3.4 Proposed Resources

The construction of a tool will focus on usability according to the studies reported in Chapter 2. Three steps were established to explore and solidify our strategy for improving the train of Computational Thinking with AR-based approaches, as depicted in Figure 3.6. After the consolidation of the term Computational Thinking by Wing (2008), society must focus on developing skills related to CT concepts to solve the problems in our lives better.

The participation of teachers or future users of the system in the process of elicitation of functional requirements is primordial to assure a high-quality final product. The proposal of the architecture of a generic tool based on AR technology to train can be visualized in Figure 8.2.

OntoCnE will be used to guide the creation and organization of the environment, along with the AR libraries, 3D objects, and rules that will be loaded.

The intent is for the AR-based LR to work in platforms that do not require high computing power and complex, expensive operating equipment to be purchased by schools. In the last step, will be studied how to start having a strategy for building new artifacts, with functionalities integrated with real activities and alternative technologies. These artifacts will provide appropriate AR-based LR according to the description of OntoCnE for training Computational Thinking.

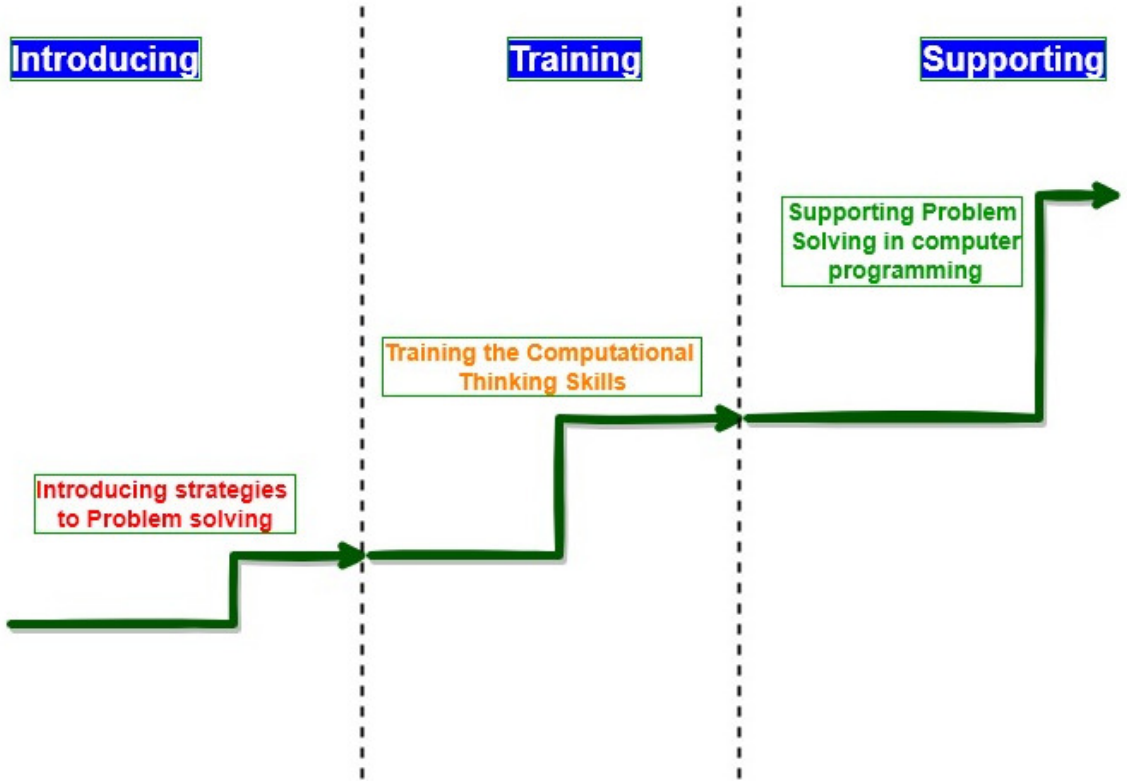


Figure 3.6: Steps to acquire and improve CT skills

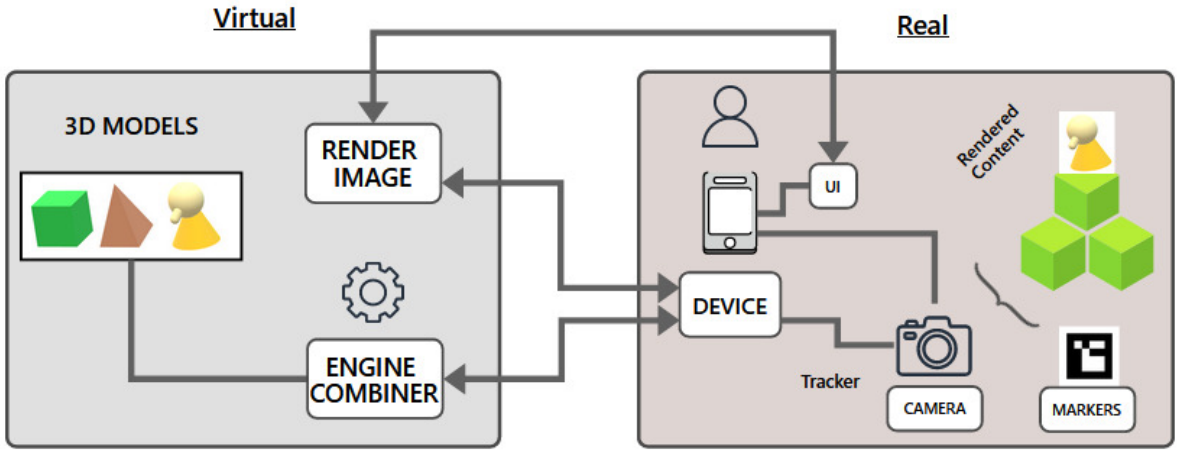


Figure 3.7: Architecture for an AR-based LR to train CT – 1.st proposal

3.5 Augmented Reality to improve CT

This section presents an overview of AR and Education along with a broad review of the state of the art. For the search of the scientific bases of indexed data in order to obtain the largest number of related works in the area, the keywords used in this research were: AR, Computational Thinking, Education, and Programming Teaching; These terms have also been translated into English and Portuguese. AR was a couple of times, applied to various processes of knowledge transfer. The use of AR in education aims at a new way of interaction that captivates users and increases their engagement and thus potentiates

the absorption of knowledge. AR is used in classrooms in areas such as chemistry, astronomy, physics, mathematics, anatomy, and others and at different levels from the primary education of children to use in universities. It is very important to maintain the dialogue about the set of elements that produce a set of behaviors for the use of technologies associated with the social environment that is used as solutions in educational activities.



Figure 3.8: Example of AR applied to Education (Jacqui Murray, 2018)

Therefore, just as Pedrosa and Zappala-Guimarães (2019) affirms, it is necessary to associate theories and educational modalities and always consider the importance of the teacher responsible for the interaction. The system can be adaptive because allows users to create, edit, and visualize their own AR projects, doing it by themselves; Interactions help on a better understanding of the main concepts. Gamification, with badges and scores, also makes the learning process easy and more effective.

Those LRs help students gain a better understanding of abstract concepts, as well as foster intellectual curiosity, creativity, and teamwork. Catalyzes interaction between STEAM and all other contents, allowing an interdisciplinary.

Initially, the use of AR in programming can be observed in the works of Lee et al. (2004). Lee presents a new approach to developing tangible AR applications. This approach allows the user to carry out the authoring tasks within the AR application being built so that the development and testing of the application can be done concurrently throughout the development process. The results have shown that the users generally found it easier and faster to carry out authoring tasks using AR. But the relationship between the development of CT and programming with AR can also be seen currently in the work of Deng et al. (2019). The work of Klopfenstein et al. (2017) presented an AR system for mobile devices of low cost, that uses a simple smartphone like increased sensor to turn a fully unplugged coding set into an AR encoding experiment, using their previous game CodyRoby. Klopfenstein states that CodyRoby AR is a renewed

version of a classic game that proves the relevance of the use of innovative technologies, that also reduce the requirements - in terms of equipment and infrastructure - for the use of tools capable of being effective in teaching and learning coding skills. The game that the author developed based on letters, can be printed at home demonstrating simplicity and accessibility, as can be observed in Figure 3.9 .



Figure 3.9: The AR-based CodyRoby game – an illustrative screen.

Chung and Hsiao (2019) proposed a mobile system with uses AR-based to explore concepts of debugging and abstraction in students. The system allows interaction with the 3D models using hand movement. The research still in progress shows how it is possible to explore AR in CT to apply in High School, demonstrating engagement among students by showing that the interface attracts attention quickly. The author's conclusions are that:

- Low-cost unplugged educational activities: simplicity and accessibility;
- Augmented sensor (mobile device) transforms the unplugged card game in an immersive experience.
- Compromise between innovative technologies and efforts in reducing requirements for CT teaching.

The work of Krpan et al. (2018) uses Visual Programming Languages (VPLs). The idea to replace textual language constructs with visual representations or blocks resulted in the development of visual programming languages (VPLs), but the visual blocks are then replaced with physical objects such as cards or cubes and are referred to as "tangible programming languages"(TPLs). The system developed has the purpose of integrating physical objects and virtual elements of AR representing a step further in the process of creating a more engaging experience for students' learning of simple programming concepts. The work of Jin et al. (2018) also deals with tangible programming with AR affirming that programming is an effective way to promote children's CT presenting a novel tangible programming tool using AR technology for young children. Helping children create their own programs by arranging programming blocks and debugging

or executing the code with a mobile device. The students can learn fundamental programming concepts, such as parameters, loop logic, debugging, etc. This system helps children to learn programming in an interesting and intuitive way.

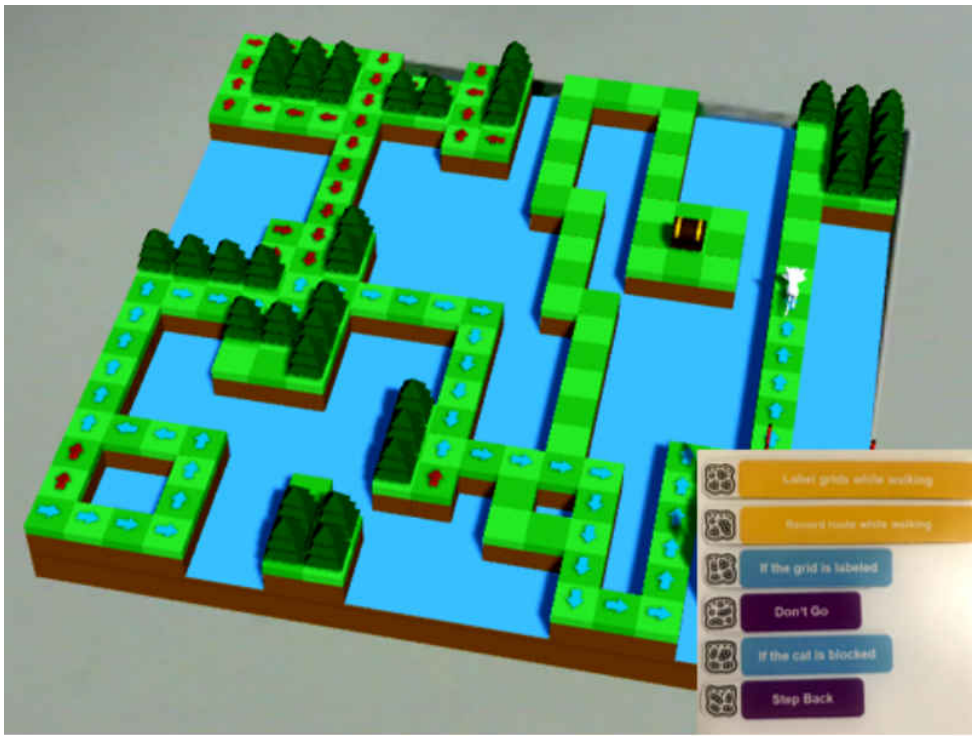


Figure 3.10: Tangible programming tool for helping children learn DFS algorithm (Deng et al., 2019)

The similar work of Deng et al. (2019) presents a proposal of a tangible programming tool designed to help children learn the Depth First Search (DFS) algorithm with AR technology as can be seen in Figure3.10. Combining the visual presented in AR environment and tangible cards, children can program by assembling physical objects and get real-time feedback from the virtual scene.

The results of studies reveal that the huge popularization of AR tools is due to the fact that they aid students have better learning efficiency than using normal systems. In addition, AR systems also made students have improved understanding in terms of system usability, flow experience, and user perception, thus enhancing the great research niche related to AR and CT or CP.

In the 2000s Wing (2008), said that CT would influence all fields of action, thus raising the educational challenge of our society. It is necessary for society to think and develop new teaching/learning tools suitable for CT training. Wing also showed how social media has added a new industry segment to our economy, investing in Virtual and AR technologies. In the evolution of technologies, the authors Teng et al. (2018), present an AR learning system for visual representation and interaction in learning 3D application programming. The author demonstrates in his work results that, with AR, the students had better learning efficiency than the common system. In addition, Teng and colleagues claim that students have a better perception of usability, flow, and usage.

In the sense of what Figueiredo and García-Peñalvo (2018) discusses in terms of programming, one cannot

simply follow a traditional system of exposing the syntax and semantics of a language. It is necessary to carry out a constant and individual assessment, drawing a profile of the student's skills. That system suggests exercises and automatically evaluates the results so that the teacher has key information to increase student motivation and success. It was observed in this work that tasks concerned with programming repeated in a different way, reinforce the acquisition of the concepts of CT being trained.

Recently Schez-Sobrino developed RoboTIC and published another two papers, Schez-Sobrino et al. (2020b) and Schez-Sobrino et al. (2020a), that corroborate the ideas presented so far. The different components that are integrated with the RoboTIC architecture are provided thanks to the use of AR and game mechanics designed to motivate students, but their system requires high-cost wearable equipment.

The difficulty of learning programming can be reduced by using tools and graphical representations associating real-world elements with specific programming concepts. Shows the concepts of CT in metaphors associated with AR is actually the main motivation of this Ph.D. project. To succeed in reaching this target, it is important to work with current technologies, such as ARCore, ARKit, Vuforia, etc.

The works (Gardeli and Vosinakis, 2020) and (Gardeli and Vosinakis, 2019) suggest how to use RoboTIC in the classroom, first explaining the concept of programming and then letting students play the related game level to check if they really understand this concept.

Part II

AR-based Resources Creation

Chapter 4

Training CT, a first approach

This chapter shows the relationships between **OntoCnE** and the techniques initially chosen to train CT using AR. As argued in the previous chapter, it is crucial to have adequate resources to train the different skills involved in CT. The more resourceful, motivating, and effective, the better students will shape their minds by learning the skills. Some pictures with fragments of OntoCnE will be shown for a better understanding of the concepts and principles. In Figure 4.1, can be observed skills and attitudes a programmer must have to program well are grouped under the name of Computational Thinking (characterized in the referred picture). It is possible to mix technological facilities and AR to build learning tools. Learning Resources with Augmented Reality will increase student motivation as Cai et al. (2019) shown in their work.

Applying AR resources as a teaching tool not only creates a learning environment but enables students to understand the general levels of programming and how to think algorithmically to arrive at a solution. The tasks performed by students in LR activities can not be too difficult or too easy to avoid students' demotivation. The research methodology adopted to carry on this doctoral work prescribes the execution of a sequence of activities that produces an innovative product. Observing carefully the created artifact, it is possible for the researcher to better understand the problem and have a better idea to improve the design process and consequently the quality of the product under construction.

In the next sections, some prototypes will be shown applied to the visualization of complex structures, using as a use case, a family tree in AR. The artifacts to be developed aiming to impact on the development of CT using AR, shall assure that the interaction with the virtual objects will be during the use of the tool, not just showing a simple 3D object to the student. Figure 4.2 shows another fragment of OntoCnE that describes the concept of *variable* used in computer programming and relates it with one of the skills that characterize CT.



Figure 4.1: Computational Thinking characterization through related skills and competencies

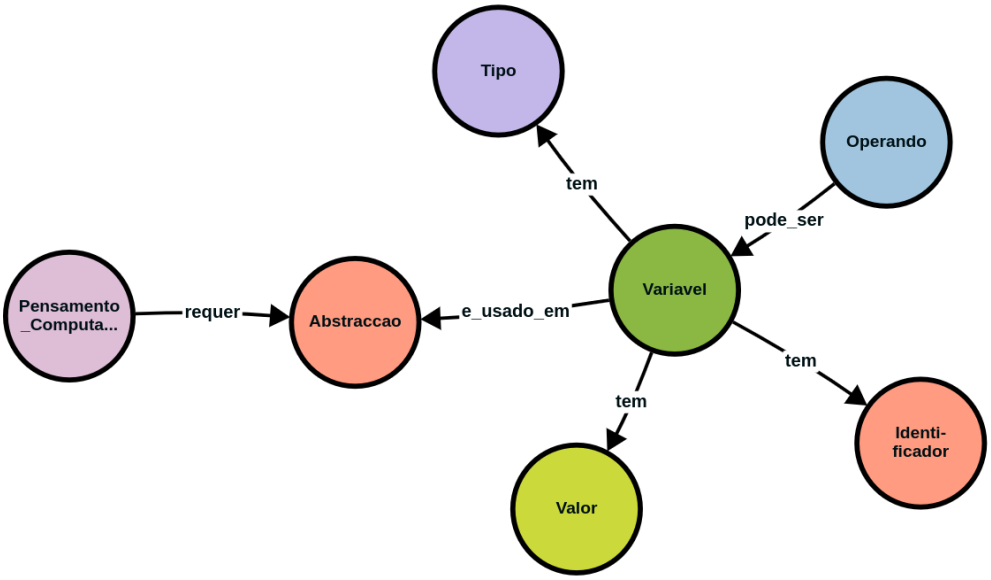


Figure 4.2: 'Variable' and other related concepts of CP and CT

4.1 Spatial Geometry in AR

To illustrate the potential of AR-based LR to introduce concepts such as abstraction, variables, and data types, it is presented to support the teaching of Spatial Geometry. In the example presented in Figure 4.3, a system that creates 3D geometric figures seen in AR. The student changes the properties of 3D objects and visualizes immediately their shapes in AR.

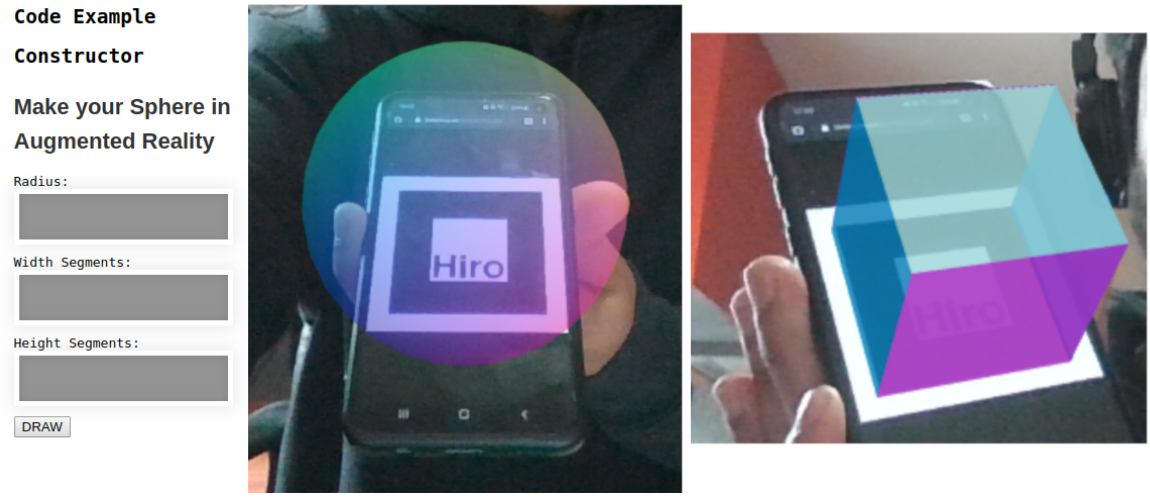


Figure 4.3: Example of 3D geometric figures

As AR contributes to the development of skills related to CT, all the Plugged Learning Resources projected were guided by this idea.

The library *AR.js* (Etienne, 2019) was used for prototyping the first attempts to create resources to introduce concepts related to CT. The library *AR.js* is a lightweight open-source library for AR on the Web, which supports features such as Image Tracking. It is essentially a JavaScript framework acting as a port of ARToolkit. Its goal is to be able to use AR on web browsers without losing performance. The prototype uses a 3D Force-Directed Graph in AR, which is a web component to represent a graph data structure in AR using a force-directed iterative layout. This makes use of *AR.js* with A-Frame for rendering and *d3-force-3d* for the layout physics engine.

4.2 Family tree in AR

There is a lot of research underway on 3D data visualization in AR, especially in the field of Immersive Analysis and analysis of medical volumes, as suggested by Sielhorst et al. (2006). Luboschik et al. (2016) claims that among the fundamental aspects to be considered in AR are linear perspective, relative sizes, parallax of movement, and binocular disparity. It is also important to show here that AR allows us to visualize information in 3D, thus being able to build analogies to explain complex concepts. Continuing the presentation of the OntoCnE fragments, Figure 4.4 shows how the concept of Data Structure is related

to other programming concepts in order to state what the programmer must understand to explore this subject.

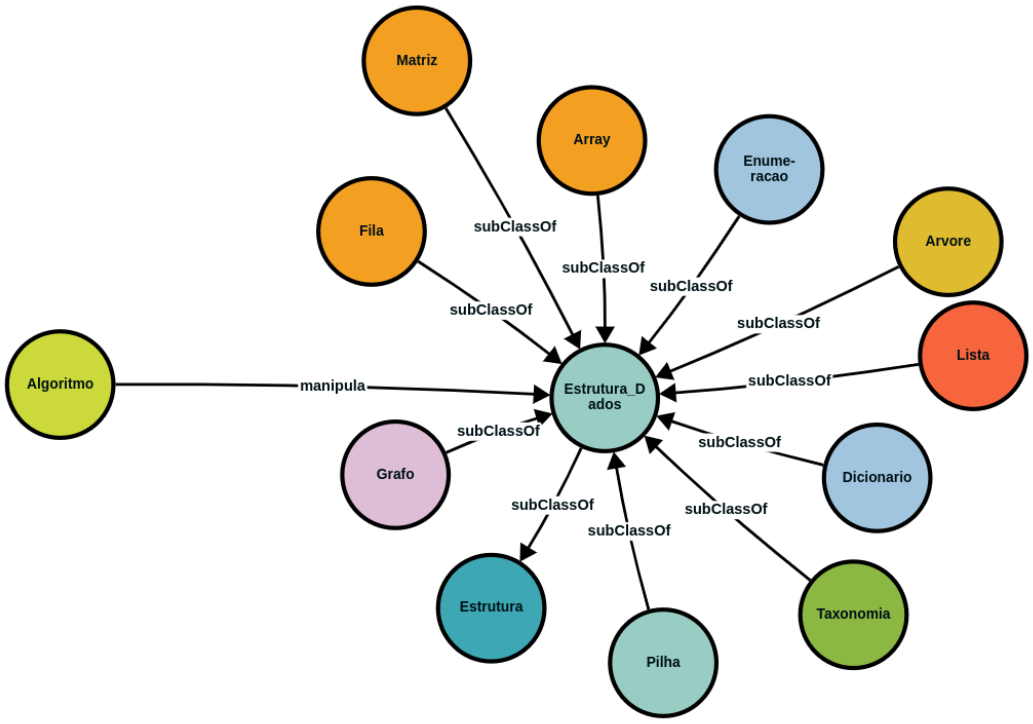


Figure 4.4: Concept approached by Family Tree application

The purpose of the tool to visualize family trees, discussed here, is to allow the user to understand the structure of a network of related data, reducing the degree of visual disturbance. The three-dimensional system allows for the display of an amount of data, colors, and shapes, without leaving the environment overloaded. Unlike a two-dimensional presentation, in which a greater amount of information, colors, and shapes tend to negatively influence the abstraction of information by the user.

Once the developed prototype is executed from the *browser*, it is possible to add external content to the hierarchy, presented as web links, images, and complementary texts. With the prototype, the user can build a tree containing different types of information. One of the advantages of using this type of technology is that it can run on old hardware, such as old smartphones, enhancing user accessibility.

Each node in the hierarchy can represent any type of data. This information is distributed in volumes. Moreover, in the case of two nodes being more closely connected, can create a type of relation named “marriage”, which also has the literal meaning in the case of a family tree. For instance: Adeluxe and Evangelino are connected and this link is of type ”marriage”; the same can be observed concerning Thaisa and Juliano whose connection is also of type ”marriage”see in Figure 4.5.

After the tree is generated, the user can interact with the nodes and said information by accessing different context menus. Within these menus, it is possible to search the information of each node as well as insert a new node.

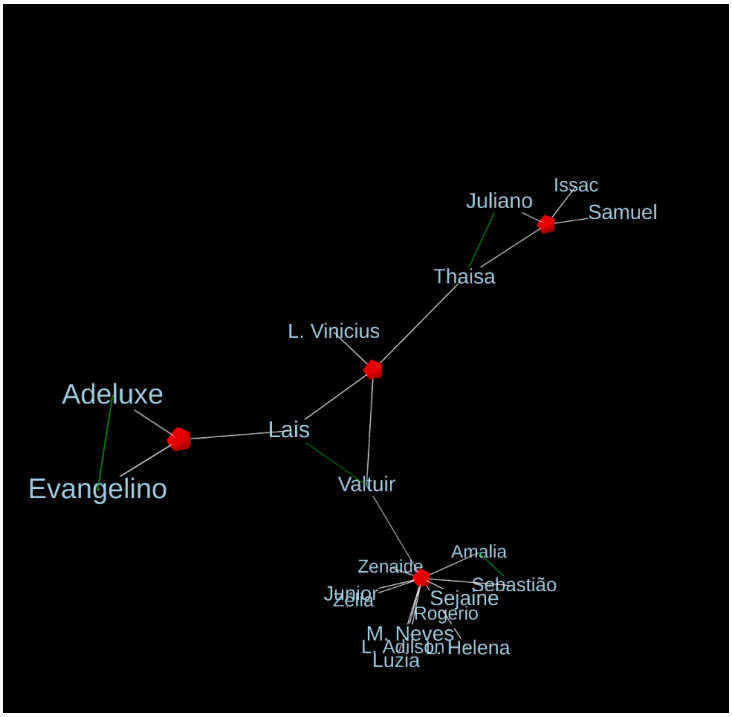


Figure 4.5: Example of Family tree in Virtual Reality.

It is important to emphasize that the prototype allows the addition of a new element. The visualization of that new element is animated and happens in real-time. Taking advantage of the best practices of AR, it turns out that the effects can be used to teach structures such as Lists, Stacks, and Queues. These concepts are better understood by students if appropriate analogies are created by AR.

An important attribute of virtual systems is their navigation and interaction with the user. Once the family tree is built, the user can access, within each node, the complementary information, for example, personal data, professional data, or medical data. Each node has a *JSON* object representing the information that it contains. To view and edit the node information, a text area is available for the user, as shown in Figure 4.6. After saving new data, it is verified if the input of the user has a correct *JSON* format. Using the tool, detach the nuances of using AR to the usual one used to increase and decrease the scale of the graph. Navigation allows the user to identify connection points, thus locating family members. Figure 4.6 presents one of the chosen family nodes and the personal data area. When the hierarchical structure has a large number of nodes, and even with the existing interaction resources inherited from the applied AR techniques, it was created an easy and understandable way for the user to visualize a specific node - a filter (Figure 4.7) using a search term and evaluating said term with a value. Using a search term that corresponds to a key in the information object, an expression that can evaluate the filter as “Equals”, “Not Equals”, “Greater than” and “Less than”, and finally a search value, the user can search for specific nodes that match the previously created filter. The tool was used for a 3D visualization of the structure. This was developed using AR.js, so the tool can run on devices that support JavaScript. Nodes were added through a web interface. The examples described demonstrated the construction of connected structures with the possibility of adding

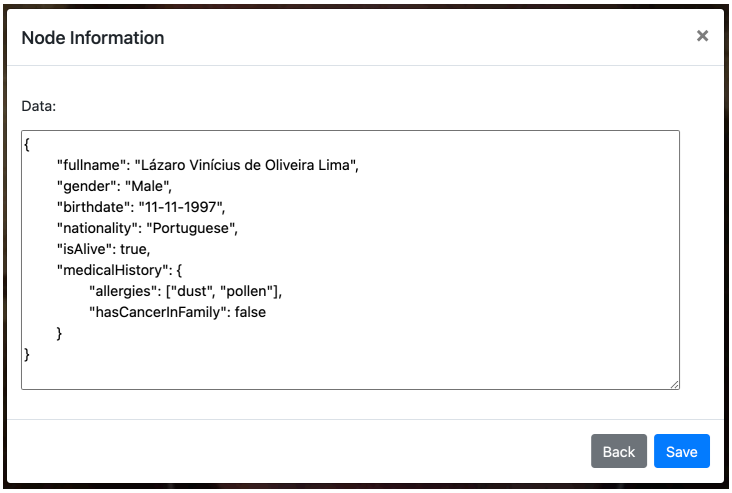


Figure 4.6: Visualization of one of the nodes in the tree and personal data form.

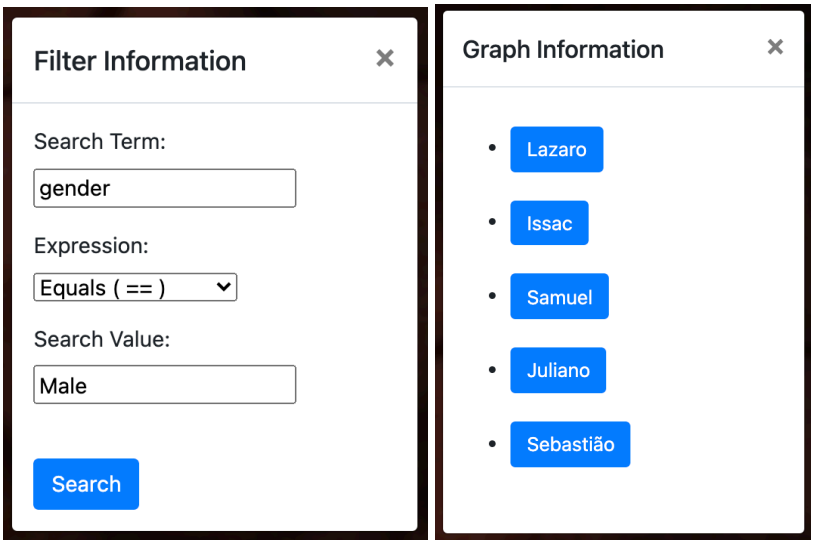


Figure 4.7: Nodes information of Nodes and Filter Information Panel

information on each element. In the next session, will be presented the representation visual of a syntax analysis tree in AR.

4.3 Lyntax - Meta-Grammar in AR

In order to show the representation of information in depth, one of the use cases of the idea presented in this work is a tool named **Lyntax**. **Lyntax** is a compiler for a domain-specific language(DSL) that enables the teacher to specify different kinds of sentence structures, and then, ask the student to test his own sentences to validate their syntax against the structural rules defined by the teacher. Given a language specification, written in the referred DSL, Lyntax generates an ANTLR grammar to define that natural language set of sentences.

When processed, an *ANTLR* parser is generated, which is then used to parse the student's input sentences

and to create a syntax tree of the input. ANTLR provides a mechanism to display in 2D format the shape of the created parse tree, allowing for a better understanding of the sentence. The syntax tree generated can then be post-processed and used to create an AR graph, allowing an even more visual and interactive way of envisioning the syntax tree. With **Lyntax** it was possible to verify the application of the ideas presented in which they are successful in explaining the effect of an algorithm on the visualized structure. The results of the tree generated by the **Lyntax** tool using AR can be seen in Figure 4.8. For more information, the tool can be accessed at *https://lyntax.epl.di.uminho.pt*.

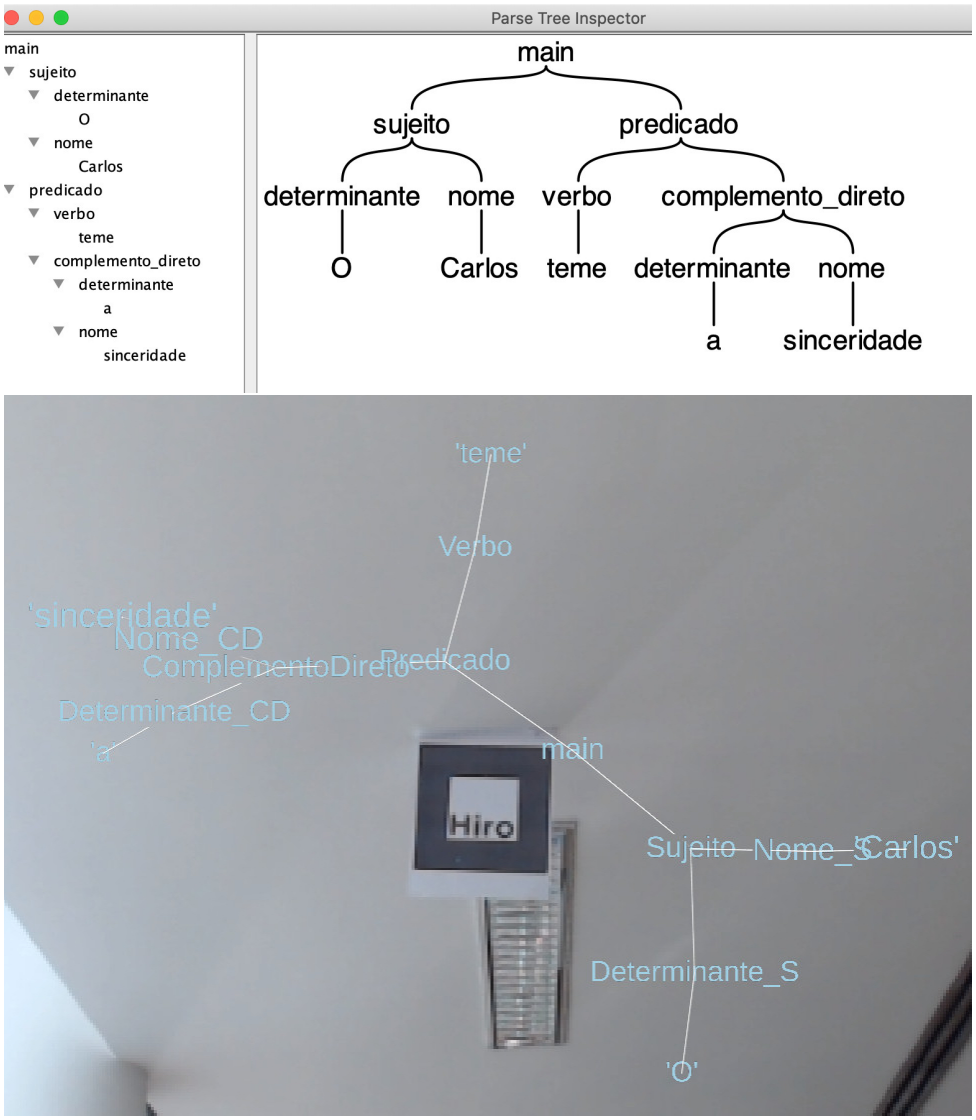


Figure 4.8: Example of Lyntax in AR.

Each component of the sentence can have different types of attributes in order to have a refined semantic analysis. Form example, in which two of the components (*sujeito*– subject and *verbo*–verb) have a common attribute, *tipo*(type). This type can be both “animated” or “inanimated”. All of the different information that guides each node within **Lyntax** is also ported for the AR graph.

Lyntax helps the user because it allows the user to inspect the attributes of each component in real-time.

The user is able to analyze the sentence while visualizing the attributes that flow over the syntax tree. This takes advantage of the best practices of AR and explores the depth of information in the tree.

The prototypes developed in the context of the project here reported, for building trees of words in AR, made it possible to apply and evaluate the proposed visualization technique.

It should be emphasized the importance of a valid strategy to show a solution to a problem in 3D. The information is presented to users in a simple and objective way, to favor the abstraction of relevant information.

With the referred prototypes, it was possible to corroborate the advantages resulting from the use of the third dimension (depth) to visualize hierarchical structures. Besides, the use of hyper-textual interfaces contributes significantly to the reduction of visual disorder with a large volume of information to be presented.

Thus, the proposed AR system allows the user to navigate, interact, and search for information within the structure, which is an important alternative to traditional methods providing an effective way to comprehend the effect of the algorithms on a data structure. As suggestions for future work, it would be interesting to work on the adaptation of the proposed technique to the visualization of different kinds of structures, such as *ConeTree*, computer networks or networking systems, complex chemical molecules, or other types of hierarchical structures. Another idea for future work is the integration of this tool with systems that manipulate knowledge bases. With AR it is possible to create better analogies in order to visualize complex hierarchical structures, such as a list of geographic and temporal information. In addition, the efficiency of visualization of the proposed technique will be investigated, as well as the scalability of the approach. At last, it is intended to explore the Learning Resource in an educational environment to verify its impact when compared to traditional methods.

Some limitations of the AR.js library used, found during the prototype development, led to change and evaluation of other tools. The use of Unity 3-D showed to be promising as it enables to insert specific attributes and behavior into prototypes as will be discussed in the next chapter.

Chapter 5

Training CT, a new approach

In this chapter, strategies for training CT will be presented, introducing and relating the concepts described by OntoCnE. It is important to develop new interdisciplinary activities with the aim of training CT. Figure 4.1 shows concepts directly connected aiming to characterize CT according to OntoCnE. Acquiring CT skills requires perseverance, repetition, and intensive training. One of the relevant skills that shall be acquired is the *abstraction* (remove unnecessary details to better understand the problems). After abstraction of the essence of a problem, is necessary to apply *decomposition* (dividing a problem into smaller parts so that its complexity decreases). *Pattern recognition*, is the ability to recognize similarities among known problems and the proposed one to reuse solutions. Combining the abstraction, decomposition, and pattern recognition abilities with logical reasoning, is possible to build one*Algorithm* (sequence of instructions for solving a problem). After building the algorithm, instructions shall be translated into a programming language to obtain the problem solution. After the execution of instructions, it is important to analyze the solution and the process and, if necessary, review the previous steps to improve the proposed solution. However, training those abilities is hard and requires appropriate resources. In the work of Cleto et al. (2020) or Schez-Sobrino et al. (2020b) AR is applied to teaching programming. The feedback about previous works reported in Araújo et al. (2019), Lima et al. (2020), Lima et al. (2021), Saraiva et al. (2021), motivates the research about the impact of AR for training CT. In the next section, a plugged-in activity for literate and non-literate children will be presented.

5.1 Fruit-combo AR

Fruit-combo is an AR-based LR that, using analogies with real-world scenarios, aims at developing in very young students some CT skills. The game also shows that from an input it is possible to obtain different

outputs.

- **Programming**: The game Markers are used in order to represent the instructions. Each of the cards (Markers) symbolizes an instruction or a raw material. Choosing the appropriate cards and putting them in the correct sequence allows for the creation of food products (cake, jam, or juice). This activity, which is the core of the Fruit-combo game, is nothing more than a programming task. It implements the analogy mechanism referred previously;
- **Pattern Recognition**: Pattern recognition is present in the small figures inside the cards or Markers. These figures are present so that even users who cannot read can use this application;
- **Algorithms**: In order to create any of the possible results (final products, or the outputs of the activity), it is necessary for the user to follow a predetermined number of steps. These steps change in order to reach a different solution. These steps constitute an algorithm that underlies the program discussed in the first item;
- **Debug**: After obtaining the final product, the user has to analyze if it is in accordance with the output desired, and if it is not correct, he must discover the step in which he made a bad choice;
- **Decomposition**: Having an objective in mind, in this case choosing one of the possible products to create, decompose the creation of this product in the algorithm thinking that constitute the algorithm;
- **Logic**: Prediction of the target to be used depending on the intended product and previously used targets, if they have already been used.

Figure 5.1 shows the Markers used in Fruit-combo to trigger the 3D objects that represent the cooking instruments and the ingredients necessary to create different recipes. Fruit-combo was implemented by a group of last year students during the last semester of their bach degree, that worked under the supervision of our research team. They designed the game to be played following the 4 steps below.

- 1st step: Choose a piece of fruit.
- 2nd step: Choose a cooking device.
- 3rd step: Choose the ingredients.
- 4th step: Observe the output obtained.

Each card has a specific QR-code that is recognized by the cell phone camera and is associated with one game and only one object (an ingredient or a cooking tool). Figure 5.2, shows the complete sequence of one of the recipes possible with Fruit-combo. In this sequence of pictures, as possible identify the ingredients,

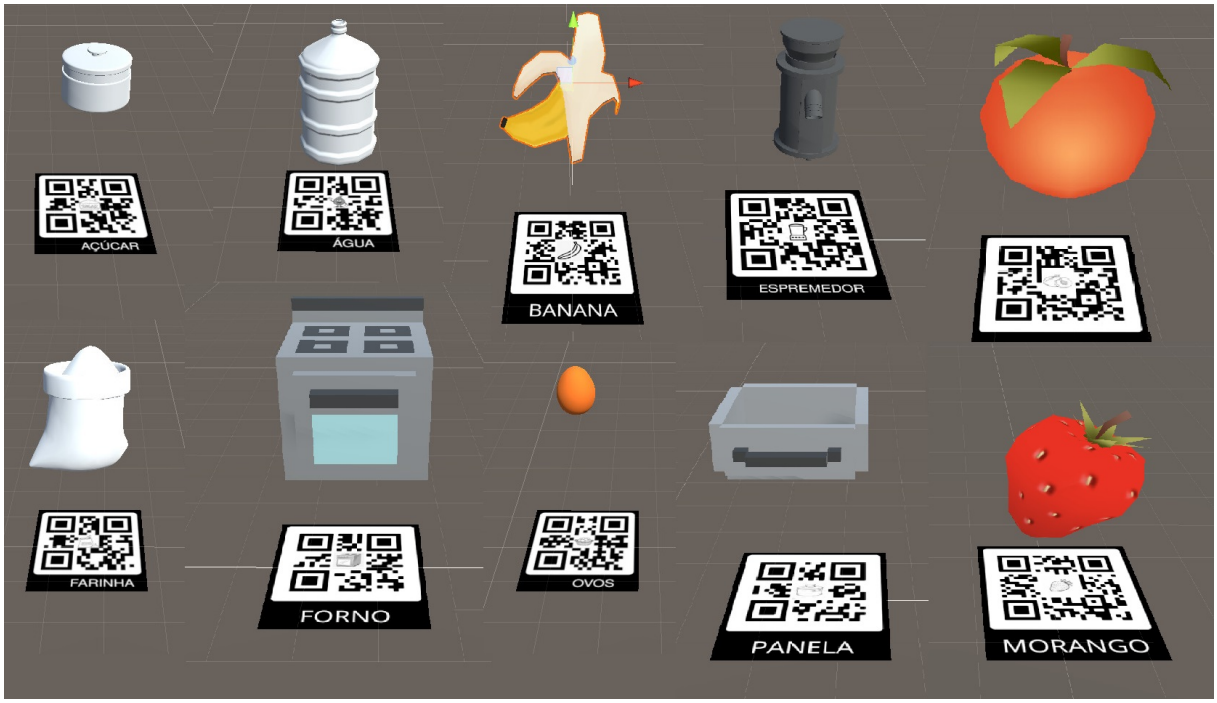


Figure 5.1: Objects 3D and respective Markers to play with Fruit-combo

fruit, and utensils of the recipe. To trigger the presentation of the final result, there is a marker that must be used, as shown in the bottom image of Figure5.2.

In the development of this application, three recipes were predefined. The user needs to use at least 5 markers to reach the final result. These recipes are described by a Control Flow Diagram depicted in Figure 5.3.

- F represents any of the available fruits; it is the start state for any valid sequence of instructions (program).
- U_1 represents the Pan.
- U_2 represents the Juicer.
- U_3 represents the Oven.
- I_1 represents Sugar.
- I_2 represents Flour.
- I_3 represents Water.
- I_4 represents the Egg.
- F_K represents the Fruitcake.
- J_F represents the Fruit Juice.

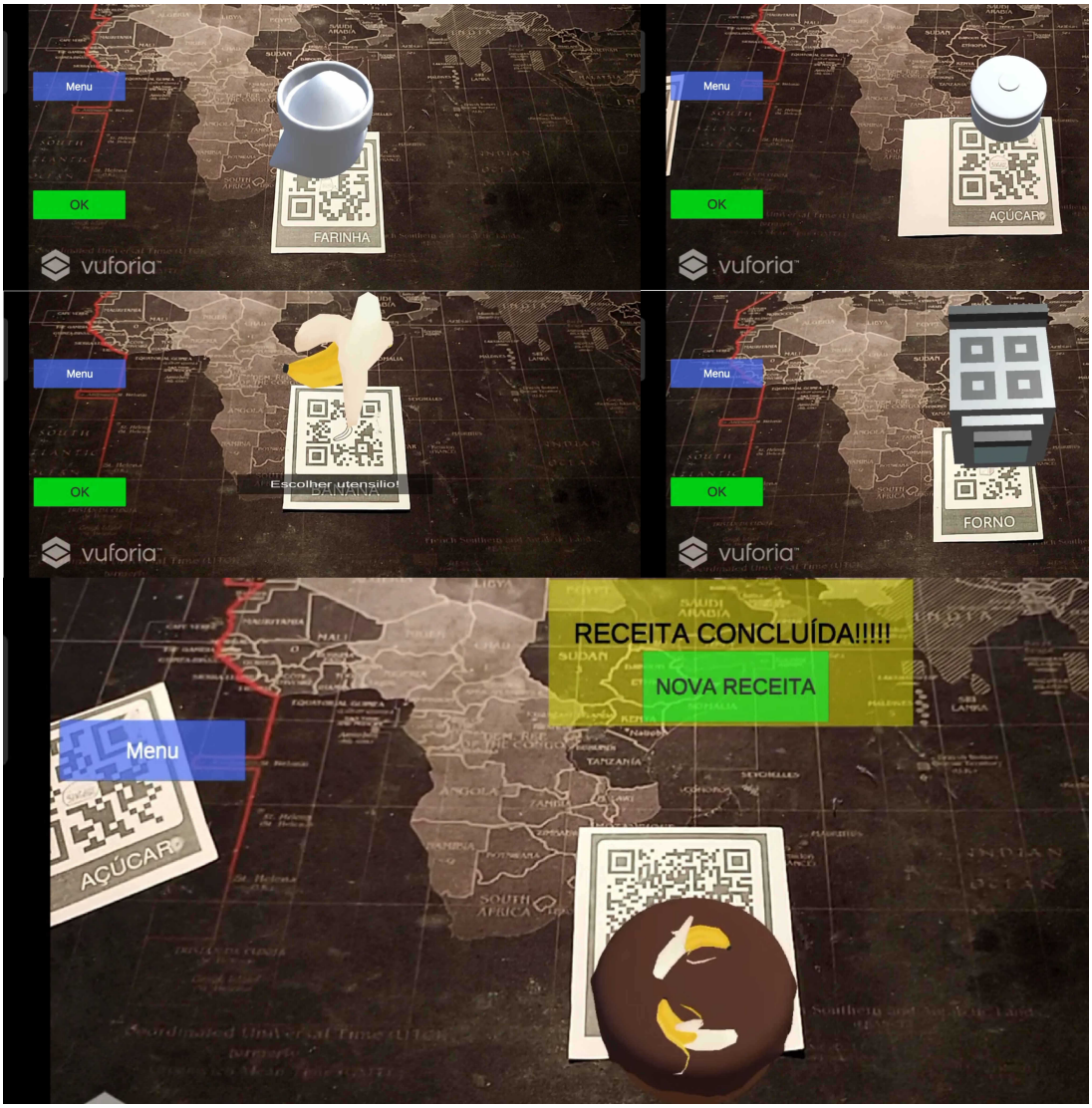


Figure 5.2: Fruit Combo with steps and final result

- F_C represents Fruit Compote.

Observing the Control Flow Graph of Figure5.3 that is used by the App to validate the correct programs and to decide the final output that must be shown, it is clear that Fruit-combo highlights the role of Abstraction and Pattern Recognition in the sense that the same Path leads to different concrete outputs depending on the concrete fruit chosen in the input.

Figures 5.4, 5.5 and 5.6, exemplify the capability of Fruit-combo App for detecting invalid card sequences (wrong Marker chosen in a given step) and for emitting clear error messages, in addition, to produce audio instructions.

Summing up this project, the main lesson learned is that it is feasible to implement an AR-based application with the objective of introducing children to programming through the training of some CT skills. The activity presented allows the user to reach several *outputs* from the same *input* which allows the user to understand

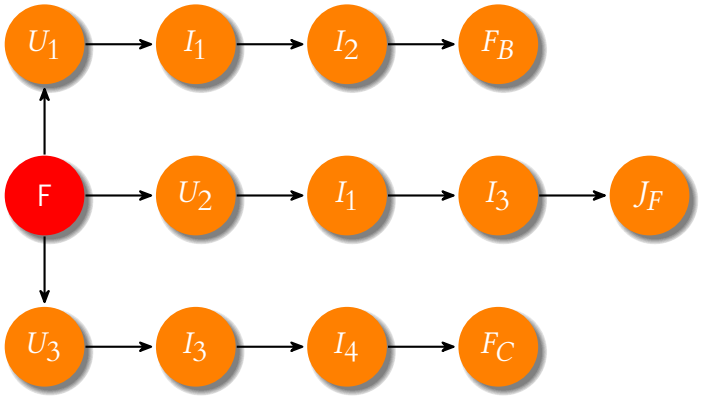


Figure 5.3: The Control Flow Graph that describes the Recipes and the valid programs in Fruit-combo.



Figure 5.4: Fruit Combo – Error Message 1: fruit cannot be chosen at this stage

that the final result will depend on the set of instructions chosen. For future development, more options for fruits, utensils, and ingredients could be inserted, which would increase the number of markers in the application and allow a greater number of combinations.

It would be interesting to invest some time in the graphical interface in order to make the application more appealing and improve the communication between the application and the user. In the next chapter, another AR-based LR for 3D character customization will be shown. The sequence and combination of cards allow for the customization of a hero in AR.



Figure 5.5: Fruit Combo – Error Message 2: a fruit must be the first choice



Figure 5.6: Fruit Combo – Error Message 3: ingredient not allowed at this stage

Chapter 6

Training CT, Make Your Hero

This chapter will be shown the developed application "Make Your Hero in AR". That AR-based Learning Resource was designed with the objective of carrying out learning activities based on the concepts of CT allowing the creation of different 3D characters. The user uses his mobile phone and six cards to interact and choose the character's attributes. Characters created can be saved and exported as a QR code. The learning activities created in this project are intended to demand the use of CT keys. The idea is to plan activities in which the user will have to make choices and to take decisions according to a strategy resorting to mechanisms like abstraction, decomposition, logic, pattern recognition, etc. Figure 6.1, shows the concepts and relationships described in OntoCnE to guide the creation of this artifact.

With the artifact created it is possible for the researcher to better understand the problem and access the approach adopted. In this way, it is possible to improve the quality of the solution attained in a construction loop until developing an effective final artifact. Because the focus of this methodology is on creating an artifact for a given problem, this artifact must be well-evaluated to ensure its objectives.

6.1 Augmented Reality SDK

To implement this AR-based LR, Unity 3-D® v.2018.4 was used. The tool is useful for building AR systems supported by Vuforia® library version 9.8. To create JSON files, the Newton-soft library was used.

To exchange information for another app, was used QR-Code with the ZWING library. Thinking about reducing energy consumption, it was decided not to use wireless transmission technology to exchange information between devices. The alternative approach chosen was saving the information produced in JSON format and then using this information to create a QR code to be read by another device. Important

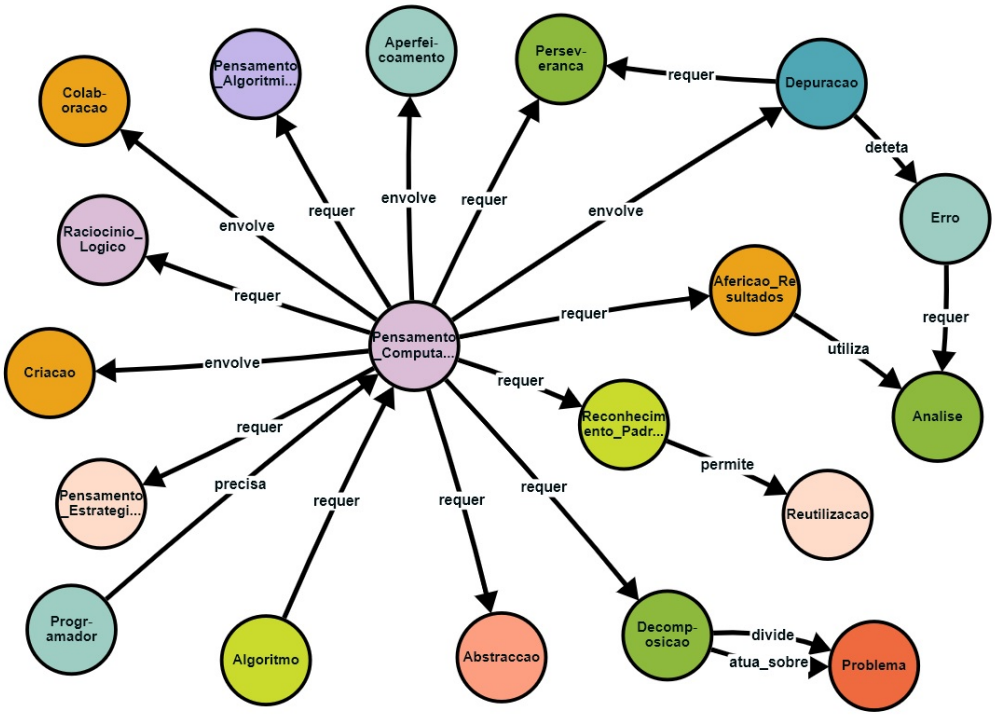


Figure 6.1: Fragment of OntoCnE to guide the creation of Make Hero in AR

to note that the activities that use the Camcorder consume more energy from the device, and on account of that those activities should be reduced as much as possible. QR-Code is generated with the information that the user has customized using the markers. The option to use the camera to read the information of another device is only available when turned on; after reading a valid QR-Code, this routine is suspended to not consume power. Also, the use of interactive menus with buttons at the start of the activity avoids using the camera reducing power consumption. So, the camera usage will be necessary just in two moments:: in Learning Activities with AR and in QR-code reading.

Vuforia is a cross-platform Augmented Reality (AR) and Mixed Reality (MR) application development platform, with tracking and performance on a variety of hardware (mobile devices and Head-Mounted Displays (HMD)). Vuforia Engine is a software development kit (SDK) for creating AR apps allowing it to recognize images and objects, and interact with spaces in the real world. Unity integration of Vuforia allows you to create vision apps and games for Android and iOS using a drag-and-drop authoring workflow.

With this experiment, was shown that AR can help students to create analogies to understand complex concepts.

Initially, the AR.js library was intended to be used; however, the rapid prototyping capabilities offered by Unity 3D led to a change in technological approach. With these technologies, it is possible to create scripts using the C# language to operate in the interface layer created by Unity3D, and also the use of libraries capable of generating visual information through QR codes. With the printed cards, the user can place them in front of the device's camera to interact with the system in AR. To prepare the system, it is necessary to

print the 6 cards or Markers shown in Figure 6.2.



Figure 6.2: Cards for interaction in the system.

CT is based on some key concepts such as *Logical Reasoning*, *Algorithm Design*, *Decomposition*, *Pattern Recognition*, *Abstraction* and *Evaluation* and changes the whole way of thinking about the resolution of a given problem. As the objective is to train CT skills in Learning Activities, the goal is to focus on the thought processes. This way the user will experience and explore an AR Activity aiming at customizing characters or recreating a character created randomly. The game presented here explores the concepts of CT as described below.

- **Pattern Recognition**: By utilizing the same cards to produce the same effect at a concrete moment of the building process, the Player acquires the habitude to recognize patterns that he can reuse in a different game to solve a similar problem.

- **Decomposition**: The challenge is to create a hero or villain. However, to attain such a final result, the Player must be capable of decompose the desired output into a set of attributes (such as: choosing which character, scale, effects, and color).
- **Algorithm**: The objective of a correct sequence of activity is to follow the steps and use the modifier cards for the desired hero as output; the importance of execute each step in the correct order enhances the principles of algorithmic thinking.

6.2 How ”Make Your Hero”works

The printed Markers are used as Game Cards for interaction through the routine that guides the user through information that appears on the screen. The activity of creating a character has five steps: Place Card Player 1 or Player 2; Place the Skin card and choose one of the available characters; Place the Power card to choose which effect will be displayed; Place Scale card to change size and display; Place Color card to change RGB colors. The sequence of steps for interaction in AR was fixed, relating to the concept of algorithm flow sequence. Figure 6.3 shows the main interface with buttons:

- **”Criar Heroi”**: allows the customization of two characters;
- **”Desafio do Heroi”**: The app generates a character with random attributes, creating a challenge to reproduce the hero with the same characteristics in the ”player 2”card;
- **”Herois guardados”**: access the panel with the list of heroes customized by the user;
- **”Como usar”**: access the panel with instructions on how to use it;
- **”sobre”**: access the panel with team information.

Users can create and save two characters at the same time. After choosing the characteristics, they can export their character through a generated QR-Code, and the character information is loaded on another device. With the printed cards, the user can place them in front of the device’s camera to interact with the system in AR.

Only with the combination of Player cards with the modifier cards (character, scale, color, and power), the system shows panels for changing the character’s attributes. To create more combination options, the AR-based LR has 4 scales of size levels, 19 characters, 10 types of Power (effects), and even the possibility of colors using 10 colors. Figure 6.4 shows the interface of ”Lista de Herois”. The first button ”Gerar QR-code”, enables the user generated QR-code to export your customized Hero. The ”Read QR-code”button allows the user to read an exported QR-code with customized information from another hero. The ”View hero”button allows loading a hero from the custom list that the user has saved.

The user can generate as many times as he wants, when they press the ”Play”button, the system will open the camera for the user to explore the Cards in AR. In the Random menu, the character will be generated



Figure 6.3: Main Menu of Application



Figure 6.4: List of user-customized Heroes stored in the app.

directly and associated with "Player 1 card"and the challenge is to reproduce a character with the same characteristics as the character generated randomly. In Figure 6.5 was shown the use of the "Skin"card, this card allows change of character available.

Figure 6.6 was shown an example of a character generated by the "Desafio do Heroi"button.

This plugged Learning Activity, using the concepts of CT, demonstrated that using a few printed Markers for AR interaction has a multitude of character customization options. The textual information is presented for each attribute generated, and the concept of abstraction is explored. And for last, the application can export information in QR-code format and students can compare and exchange characters between devices like in Figure 6.7. This activity can also be used to create stories and use custom characters as

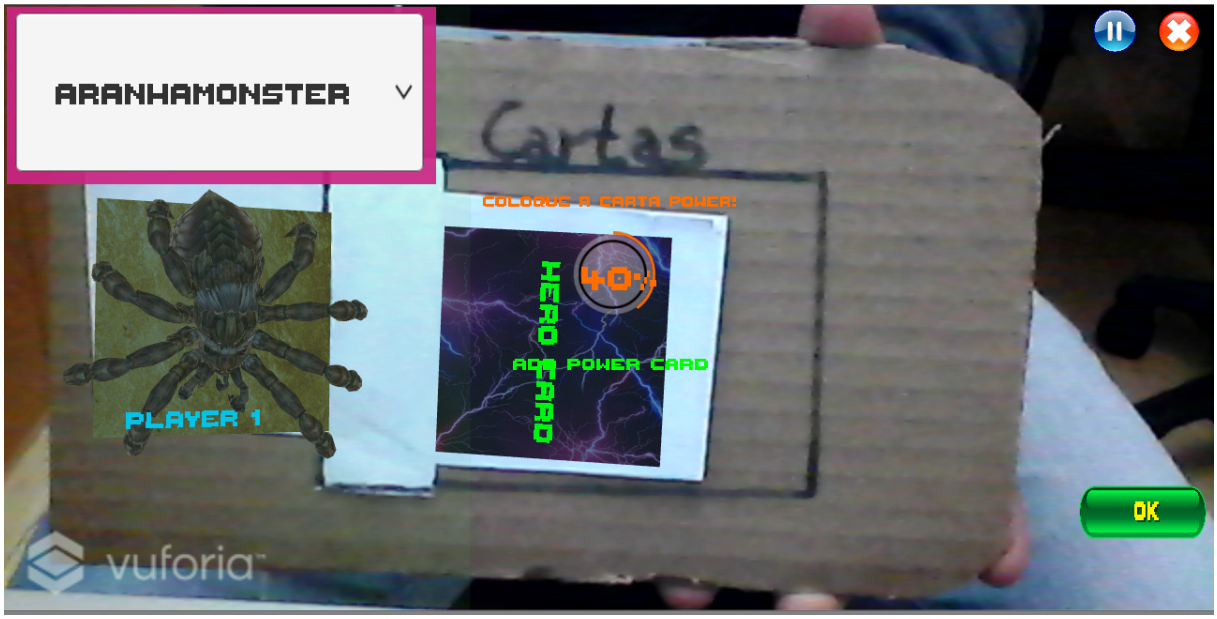


Figure 6.5: User screen shows the real environment with one of the nineteen characters available in AR-based LR.

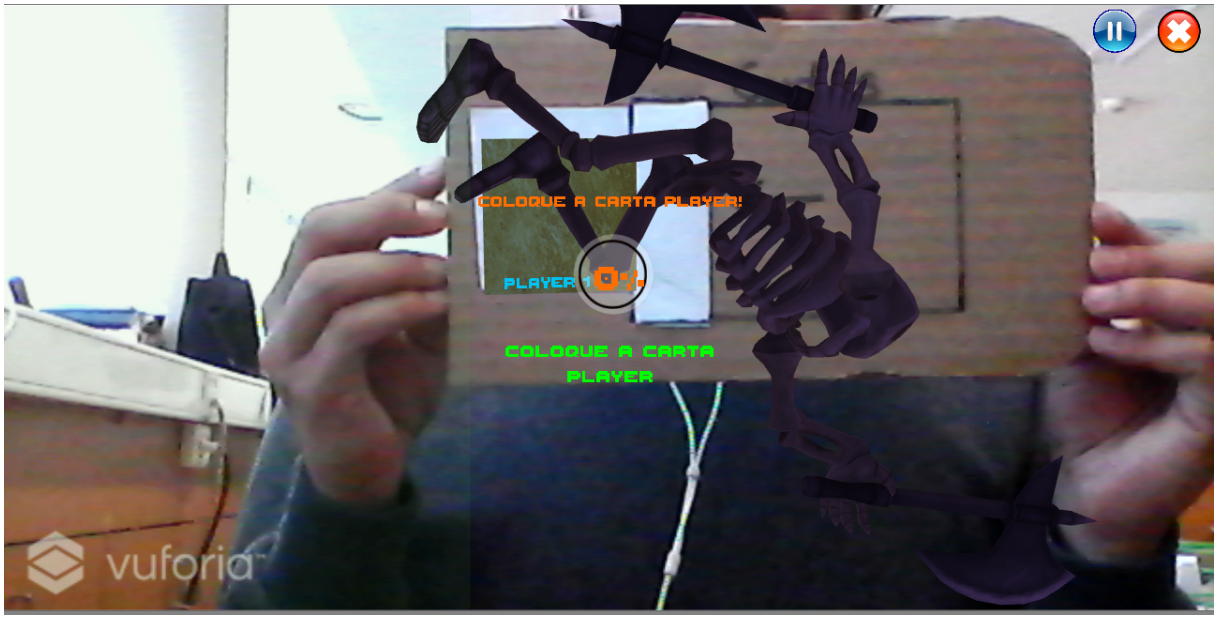


Figure 6.6: Example of Randomize hero

protagonists, involving other educational content. This tool was built using CT concepts and can be applied in areas such as History, where the teacher with students can create scenarios and reproduce moments using mobile devices that have a camera and printed markers. Users can create and save two characters. After choosing the characteristics, they can export their character through a generated QR-Code, and the character information is loaded on another device. Only with the combination of Player cards with the modifier cards (character, scale, color, and power), the system shows panels for changing the character's attributes. To create more combination options, the activity has 4 scales of size levels, 15 characters, 10 types of Power (effects), and even the possibility of colors using the scale from 0 to 255 RGB scale, having



Figure 6.7: Example of QR-Code generated of Hero

there to sixteen million combinations.



Figure 6.8: List of heroes Scene

Figures 6.10 and 6.11 shows in sequence, the screens of the Hero challenge, the user pushes the button and the system generates randomized attributes. The app generates one of fifteen characters available, size, magic effect, and color. This step of the activity aims to train the concepts of abstraction.

The system allows the user to generate as many times as he wants. When the user pushes the "Play"button, the system will open the mobile camera to explore cards in AR. In the Random menu, the character will be generated directly and associated with "Player 1 card"and the challenge is to reproduce a character with the same characteristics as the character generated randomly. This Activity uses the concepts of CT and demonstrates that by using a few printed Markers for interaction with AR associated with the number of attributes. The activity allows a great number of possibilities for character customization. This activity can also be used to create stories and use custom characters as protagonists, involving other educational

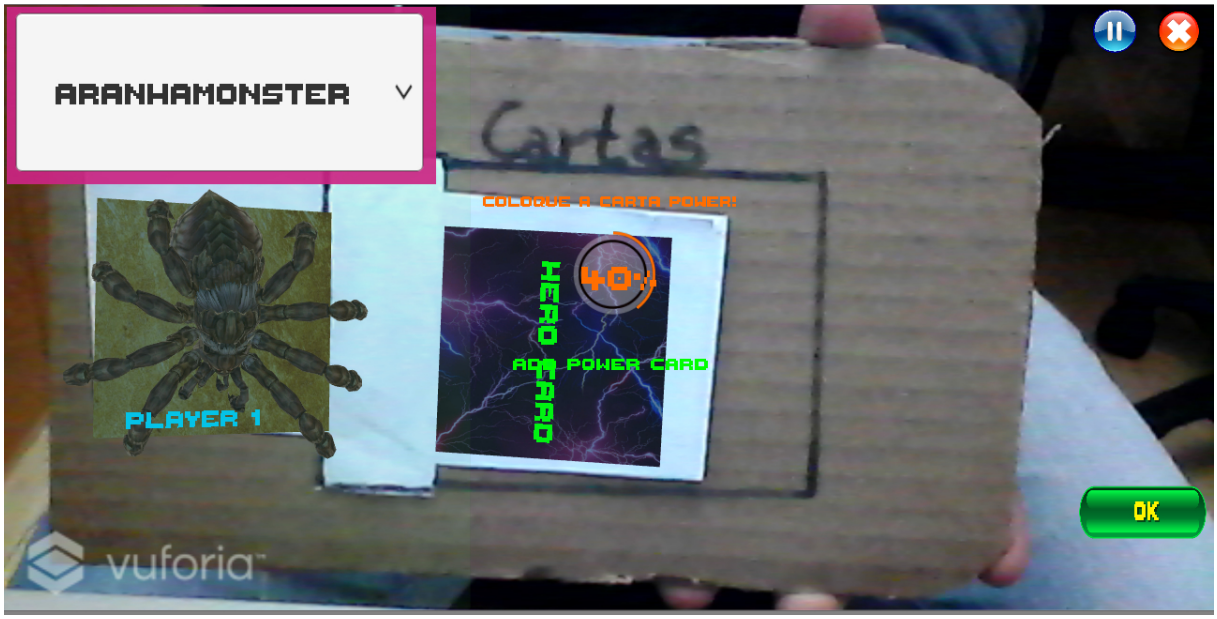


Figure 6.9: Example Panel to change character

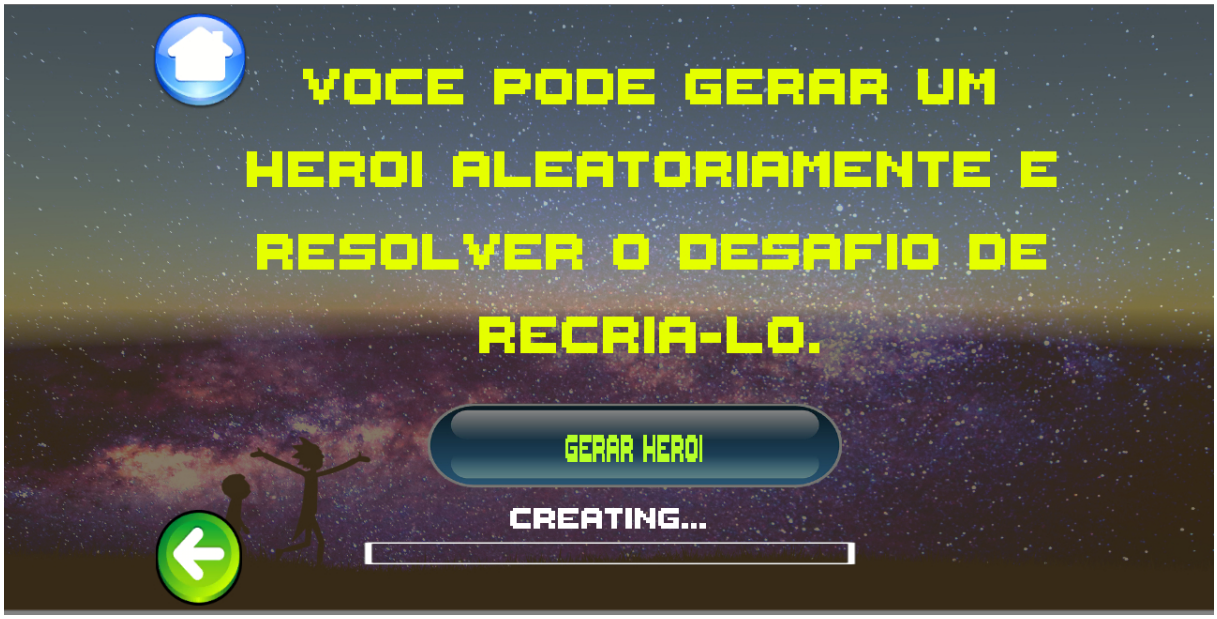


Figure 6.10: Scene of button to randomize hero

content. This tool was built using CT concepts and can be applied in areas such as the History of Egypt, where the teacher with students can create scenarios and reproduce the interior of a Pyramid or moments using mobile devices that have a camera and printed markers. The application can export information in QR-code format and students can compare and exchange characters between devices.

In the next section, will present another AR-based Learning Resource. One developed game in which the characters are shrews on terrain with obstacles to be overcome.



Figure 6.11: Example of Randomize attributes

Chapter 7

Training CT, Shrews

The challenge proposed by the Shrews game is to guide a friendly small character, in a 3-D labyrinth. The aim is to help him to travel from a start position to an end position. The player must overcome all the obstacles found along the way. The player must interact with the virtual scene shown (three different levels are available as can be seen in Figure 7.1). Through virtual buttons that activate movement instructions or actuate on drilling tools to cope with obstacles appearing in the scene.



Figure 7.1: Shrews: the screen to choose the difficulty levels

Shrews is a puzzle game that uses AR to train skills related to CT. The game was developed with the

objective of being easy to access, and cheap so that the idea can be developed impacting the training of CT.

7.1 Shrews, Overview

As a way of simplifying the combination of markers, a game board approach was used. Instead of printing the three markers individually, one simple image with all the markers aligned in the correct order was conceived, therefore creating the Shrews game board shown in Figure 7.2.

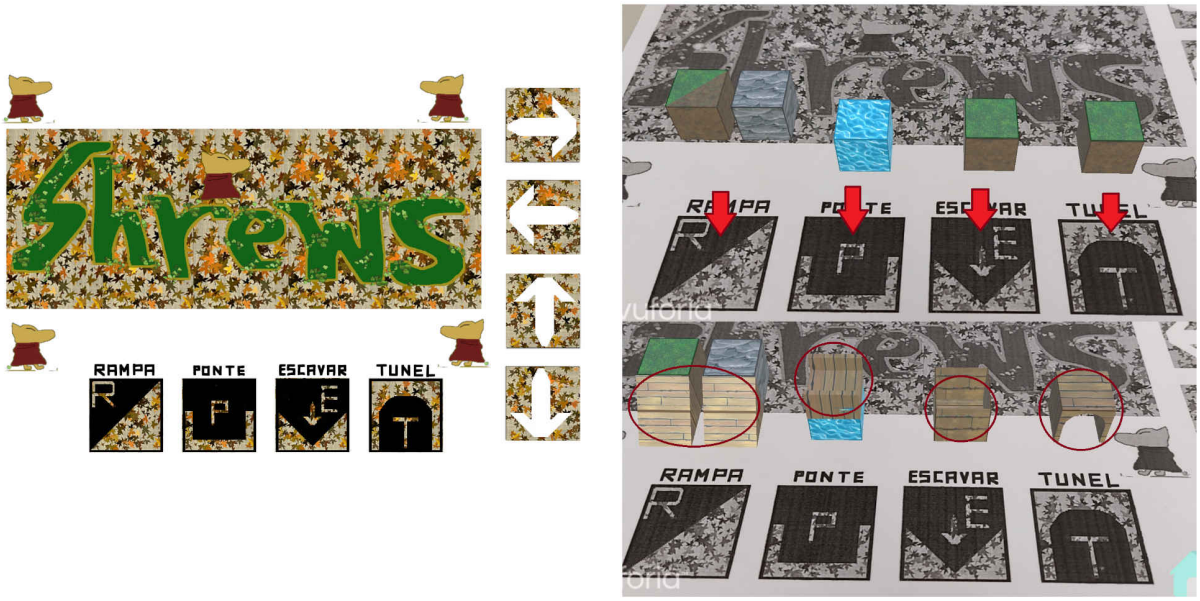


Figure 7.2: Shrews: a central area for the game and markers for movement instructions and tools to overcome obstacles.

The playable stages open up the device camera to begin tracking the markers for the display of the AR environment over the game board. To start the activity the Player must press the Play button to start the timer and activate the virtual buttons. At the top left corner, a score is shown and at the top corner right a timer is displayed. The "Jogar"option represents one of the possible three game levels. The "Iniciante"(Beginner) button starts the beginner level of the game, the "Médio"(Medium) starts the intermediate level and the "Avançado"(Advanced) begins the advanced level of the game already shown in Figure 7.1. Figure 7.3, exhibits the 4 possible types of construction that the 4 virtual buttons at the bottom part of the game board enable to operate.

The scoring system is simple, moving the builder gives 1 point, and performing an action gives 10 points. While playing the game, moving the Shrews, and performing actions, produce changes in the scenario that are directly reflected in the AR game board. This map allows the user to find different paths and use different actions to cross the obstacles. Figure 7.4 shows a possible path and the required actions (choosing the appropriate constructions) to cross the map and reach the exit. The advanced level (look

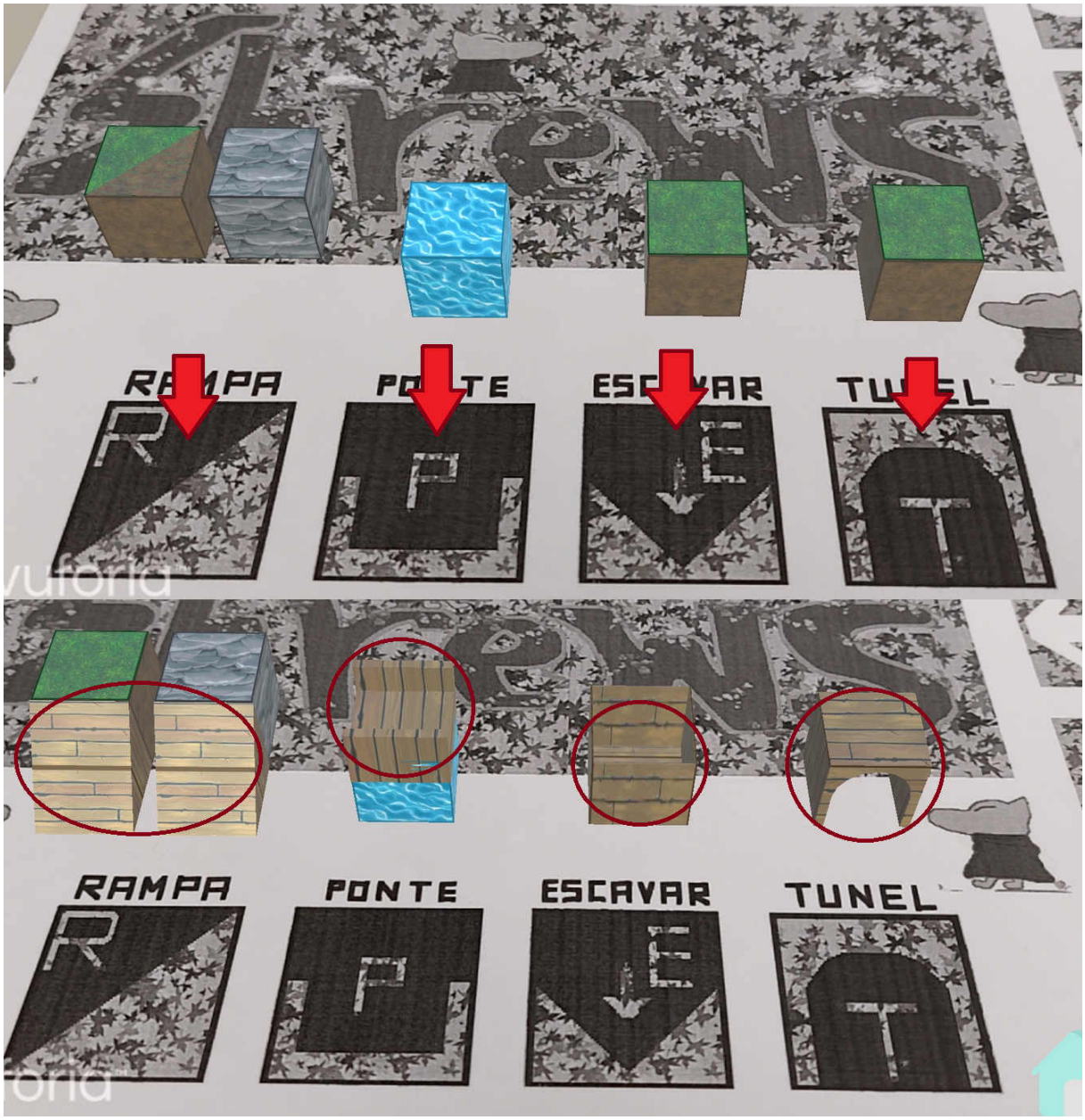


Figure 7.3: Shrews: the 4 types of construction available: a ramp, a bridge, a sink, and a tunnel

at Figure 7.5) has a more complex map structure, being composed of all types of cubes and limiting the mobility of the Player to think about the best strategy of moving out and reaching the exit.

As will be detailed in the next subsection, the four skills of CT that can be acquired with this game are: **decomposition, abstraction, algorithmic thinking, and pattern recognition**. Among games that tackle these four characteristics, there is a genre that stands out among them, it is puzzle games.

A video game puzzle that is well known and that tackles these concepts is Lemmings (Stagni, 2016), a 2-D puzzle platform developed by DMA Design in 1991. Lemming's objective is to guide a group of characters through various obstacles in a 2-D view from point A to point B.

The components that make up Shrews game are the **device**, such as a smartphone or tablet, and the **software** in the context of this doctoral. This software is responsible for the execution of the Video Game

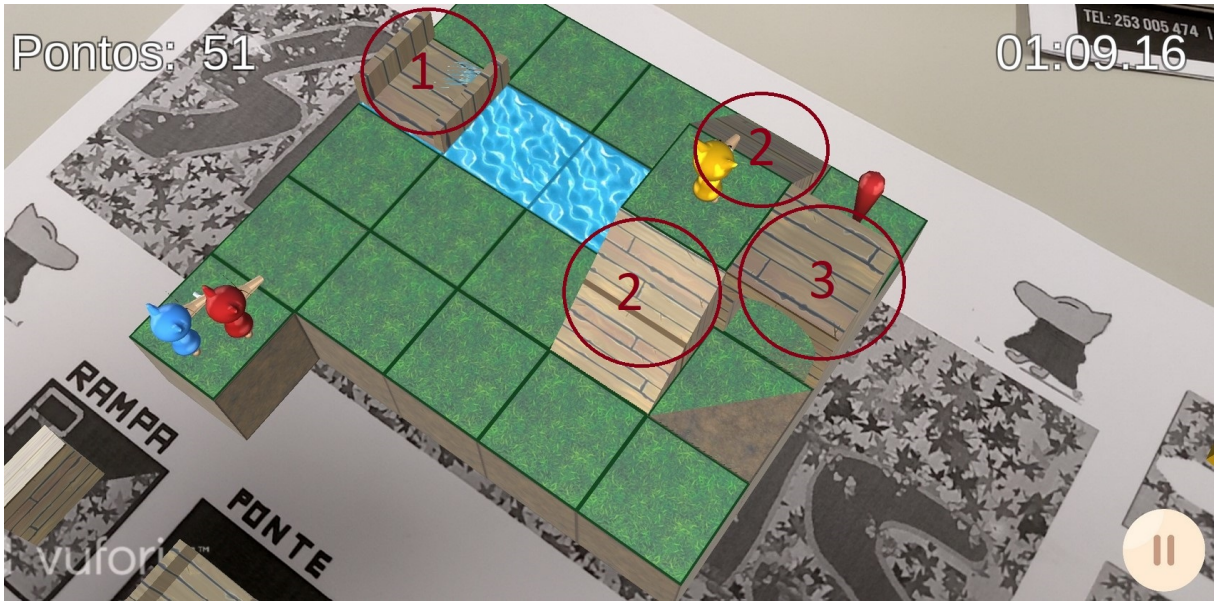


Figure 7.4: Shrews: 3 types of construction in screen: 1- bridge; 2- ramp, 3- tunnel

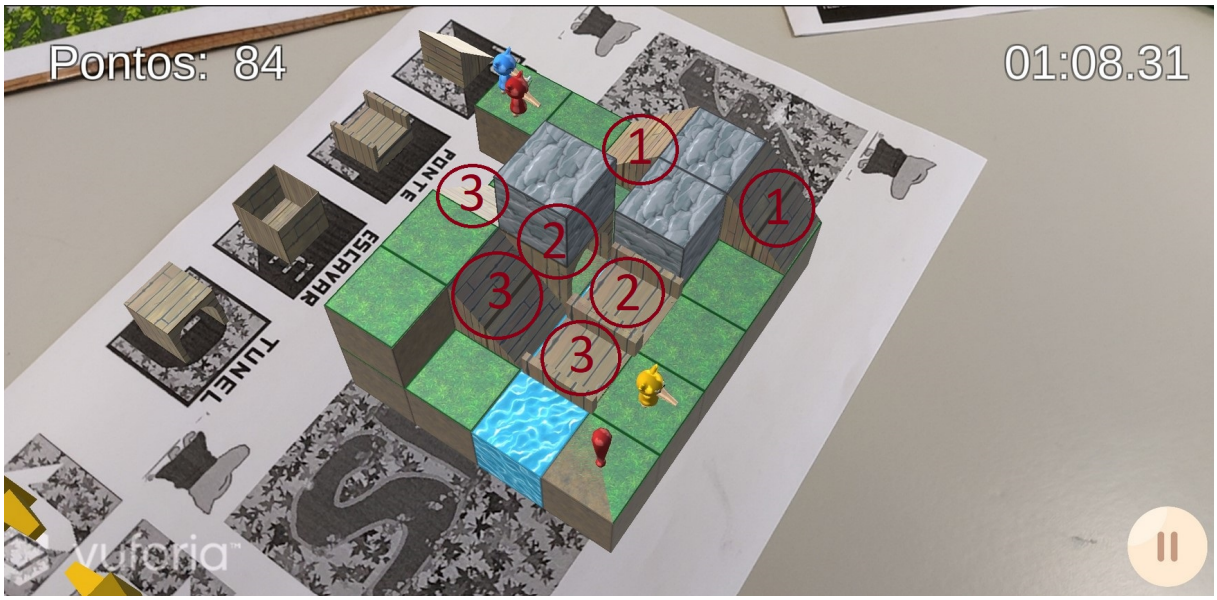


Figure 7.5: Shrews: example of a game and a possible solution using 6 constructions.

and the creation of the AR environment that the player will use as a lens to see it. The App uses a camera to track a surface to project the AR environment and identify the various AR markers to execute the desired tasks.

7.2 Shrews in more detail

The Shrews are three types of characters: **Builder**, **Adult**, and **Elder** with different shapes and behaviors, as sketched in Figure 7.6.

The objective of the game is to guide a group of Shrews over the map, piloting them from the start to the exit point. For this, the Player will use AR cards to instruct the **Builder** to construct a correct path for the

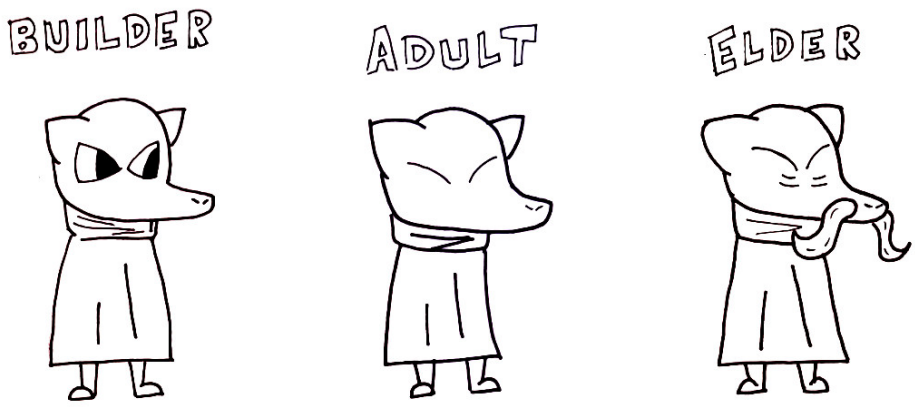


Figure 7.6: Shrews: three types of characters of SHREWS Game

Shrews. The **Adult** and **Elder** Shrews just follow the **Builder** that guides them safely across the map, as they cannot see in front of them. The Player will use cards to instruct which action the Builder will do. For example, tapping on a block and choosing a card will make the builder move to that spot to build the path forward. The remaining Shrews will walk back and forth nonstop on the pathway the Builder shrew has moved in. The game will have a scoring system based on various statistics throughout the session like the time it took to solve the puzzle, how many tools were used, and how many Shrews made it safely to the end.

Figure 7.7 is a sketch of the Player using a smartphone or tablet to read the game board and activate the system to start working with the virtual environment. Moving with the device around the map the player will be able to see the whole map from different perspectives. The cards or Markers chosen are read by the AR App causing the various tasks of the builder shrew to be executed.

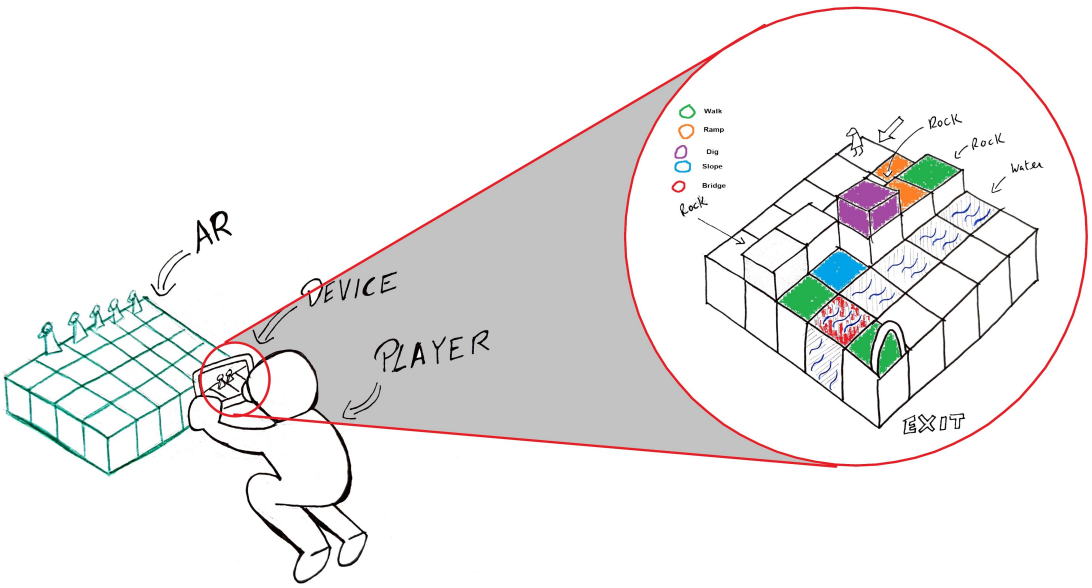


Figure 7.7: A sketch describing the Player using user interaction with the game.

The game proposed has more than one way to be solved. The map holds various normal blocks, rock

blocks, and rivers composed of water blocks. The elementary operations that the Builder can perform, illustrated in Figure 7.8, are as follows:

- **Move**: Instructs the Shrews to go a step (a block) forward or backward, turn left or turn right.
- **Ramp**: Creates next to the selected, or more, dirt blocks a ramp allowing the shrews to go up or down to another block; depending on the direction they are walking they will climb, or slide down the ramp. It is noted that the builder shrew does not slide down the ramps, only the adults and elders, depending on how many ramps elders slide down the more hurt they get on landing. These are the only buildings the builder Shrew can construct without needing to shape a block.
- **Bridge**: Constructs a bridge over blocks of water or more connecting blocks over a space, allowing the shrews to walk over the water blocks.
- **Tunnel**: Builds a tunnel through a block to move to the other side, this is only possible on dirt blocks and not rock blocks.
- **Dig**: Destroys a selected block near the builder Shrew to open up space so that the path can go through it.

As the objective is to train CT skills, the gameplay will focus on the four skills referred above:

- **Pattern Recognition**: Observing the use of building tools and their effect on the blocks to give pathways, Players will start recognizing patterns to solve similar problems. Observing the behavior of the shrews and reusing the patterns found will help to guide them better in future situations.
- **Decomposition**: To solve the entire puzzle, it is necessary to identify sub-problems (an obstacle each time) and cope with one after another. This is nothing more than problem decomposition.
- **Algorithm thinking**: The objective of the game is to design an algorithm that leads the Shrews from the Entry point to the Endpoint.
- **Abstraction**: The difficulty of the puzzles is measured by the number of existing blocks and the overall dimension of the map. It is important to abstract how flat surfaces of blocks can be paths as opposed to groups of blocks in different heights, as well as the different types of terrain. Also, the perspective view of AR to visualize the map from all angles gives the player a sense of analysis and strategic planning.

Figure 7.9 uses colors to illustrate the blocks and the tasks associated that the builder shrew will perform. Illustrated in green are the blocks indicated to walk over, followed by a block in brown where the builder will construct a tunnel, followed by red where a will be constructed a bridge to cross the water, and the remaining tiles in green to walk over to the exit. This is a more simple approach to this puzzle as it is straightforward, without going up and down to cross the higher blocks.

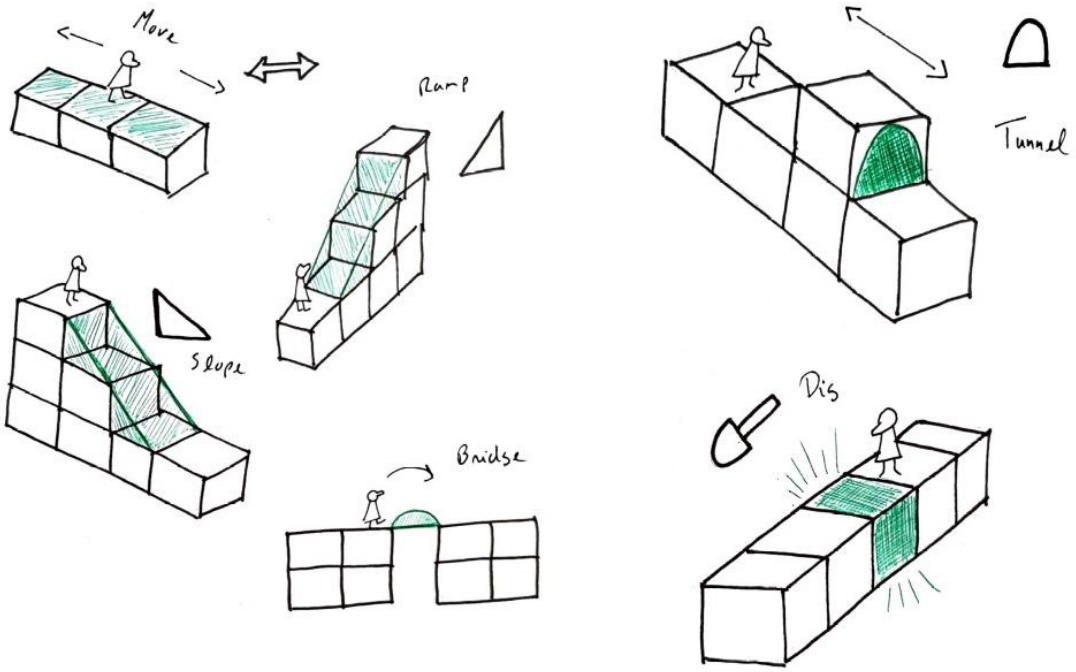


Figure 7.8: The elementary operations that the Builder can perform.

To classify the proposed game an ontology for game classification was used. **"Ontojogo"** designed by Teixeira et al. (2020), is a formal specification of a vocabulary that can be used to identify and evaluate the properties or attributes of games in order to clearly characterize them. Using the expertise of OntoJogo authors, the ontology allows for classifying the games according to different perspectives or different categorization axes.

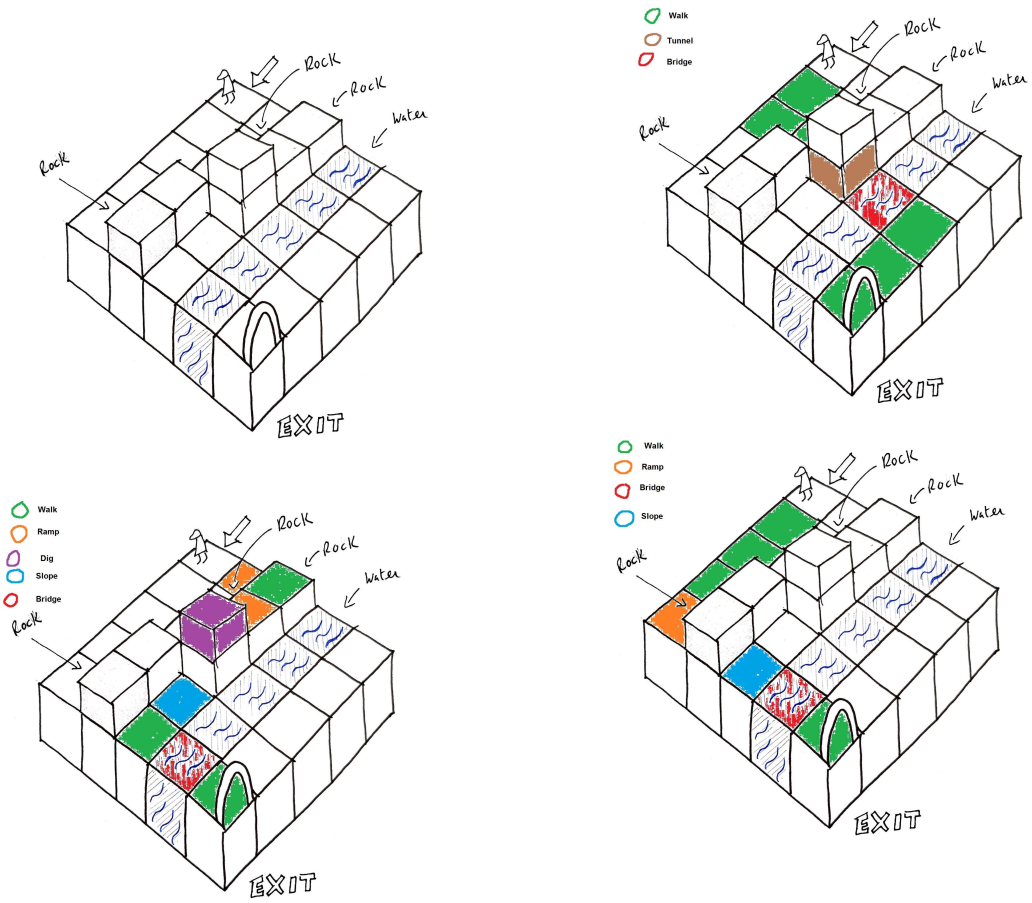


Figure 7.9: Examples of puzzle maps and respective solutions.

Listing 7.1: Classification of Shrews in **OntoJogo**.

```
1
2       Shrews =iof => Game[name="Shrews", description="Shrews is a puzzle solving game
            ↪  where the player helps guide creatures over a map.", age_rating=7,
            ↪ storyline="fiction"];
3       Shrews =is_available => Digital Offline;
4       Shrews =has_mode => Casual;
5       Shrews =has_perspective => Third-Person;
6       Shrews =with_input => Movement-Based;
7       Shrews =with_input => Touch;
8       Shrews =has_player_number => Single Player;
9       Shrews =has_progression => Level-Based;
10      Shrews =belongs_to_platform => Mobile;
11      Shrews =belongs_to_genre => Puzzle;
12      Shrews =belongs_to_genre => Strategy;
```

Listing 7.1 is a formal description of Shrews AR game written in OntoDL DSL and organized according to OntoJogo, emphasizing its main properties as a serious game to train CT.

7.3 Final Discussion

In order to train skills like Algorithmic thinking, Decomposition, Pattern Recognition, and Abstraction. It was discussed how Video Games help shape the way of thinking, improving different and relevant strategies for solving problems. Previous games, like CodeCubes and HyperCubes, have proven to be successful in teaching CT due to the AR models they use; however, that process was experimented with children working under specific technological environments like computer programming clubs. On the other hand, Shrews aims at making a difference with a real personality, able to captivate a wider range of people; to attain that purpose, Shrews has a proper design and style, as well as easy to use interface. The growing popularity of technology in our society was pointed out, as well as the Video Games that utilize it in their core and employ good uses of the technology in their interactions and practice. Combining the two subjects the prototype discussed in the chapter is an AR-based 3-D game that proved to be usable to train its players to develop CT important skills. This simple prototype shows that a serious game helps develop the referred skills with an immersive and interesting technological approach. Moreover, the development of that prototype emphasized the validity of the chosen strategy to solve properly a problem in 3D. The information is displayed to users in a simple and objective way, seeking to limit the number of secondary resources used in the presentation to favor the abstraction of relevant data.

Chapter 8

Aiding CP, LVL

To introduce the latest but not least AR-based LR, it is necessary to discuss new teaching strategies. This AR-based LR has the intention to create a new way for Beginners in programming to learn data structures. Work by Neamtiu et al. (2005) presents a tool to compare source code from different versions of a C program using the partial abstract syntax tree matching approach. The author explores an interesting approach to show how important it is to follow software evolution issues.

In the evolution of technologies, the authors Teng et al. (2018), present an AR learning system for visual representation and interaction in learning 3D application programming. The author demonstrates in his work that, with the AR approach, the students got a better learning efficiency than when using the common system. The author Dass et al. (2018) evaluated two interactive AR coding environments:(1) head-mounted AR with Microsoft HoloLens, and (2) mobile AR with ARKit on an iPhone. The author affirmed that participants enjoyed using mobile AR the most, emphasizing the easy access and manipulation of the system. Another author Agrahari and Chimalakonda (2020) proposed an Augmented Reality-based software application to teach data structures with the help of abstract syntax trees. Using Unity with Vuforia, to show concepts of data structures Narman et al. (2020), developed an AR application that visualizes some operations coping with Array list, Linked list, and Stack. The author creates a learning environment for students based on AR. The author Card (1999) says: "Visualization holds great promise for computational science and engineering, provided we can meet the immediate and long-term needs of both toolmaker and tool users". However, there are different types of visual representations of this information. This project allows for the three-dimensional execution of a tool for the development of Augmented Reality that supports the teaching/learning/training process. In the work of Lima et al. (2021), the search for ways to visualize different types of data, their connections, and their relationships, has begun, using family tree analogies and text structures to present information and its relationships. The cited work allowed for the investigation of

information arrangements and organizations in a 3D environment.

In the next session, an AR-based Learning Resource to support the comprehension of imperative programs, inspired by the previous investigation above referred to, is presented.

8.1 LVL, overview

As said in Chapter1, the methodology used in this research was Design-Based Research (DBR) proposed by Collins (1992). This methodology focuses on three iterative phases: (1) analysis and exploration, (2) design and construction, and (3) evaluation and reflection. Similar work has been done by Narman et al. (2020), but it is necessary and feasible to go further. In the investigation, greater freedom is sought in textual writing to obtain an immersion in the visual representation with interaction in the structures. Bearing these important points in mind, LVL, a small language capable of supporting the creation and manipulation of data structures was designed. That language allows the Programmer to declare structures such as lists, stacks, and queues, as well as provides special operators to handle these structures.

Figure 8.1 and 8.2 shows the architecture of the overall system that can recognize a program given as input and create an Augmented Reality interactive scenario to help people comprehend the semantics of that input program. Continuing from previous research described in the previous chapters (see Lima et

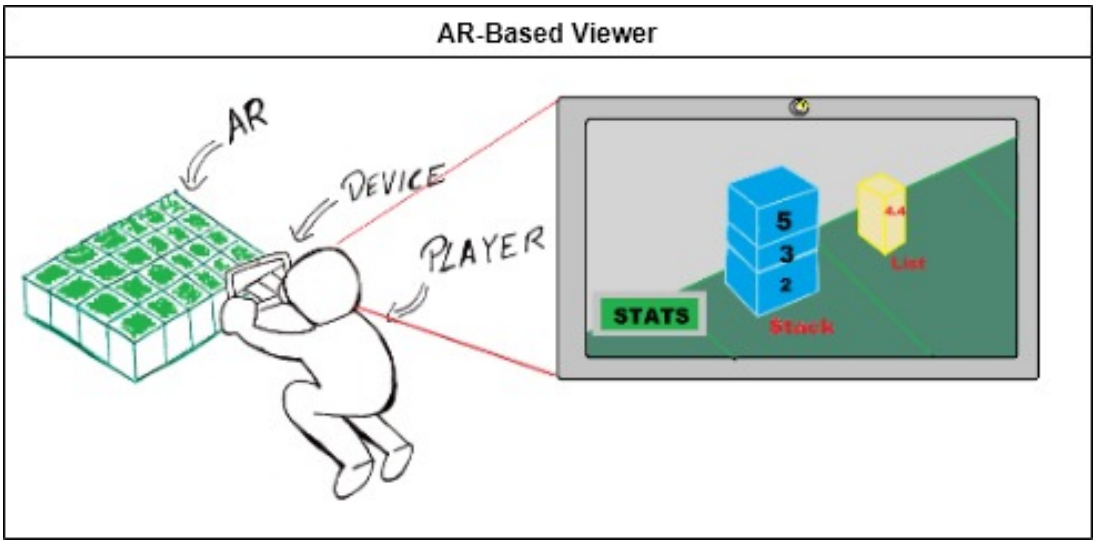


Figure 8.1: LVL program viewer App

al. (2021); Lima et al. (2023b); Saraiva et al. (2021)), the adoption of mobile devices is attributed to their considerable popularity and the agile interaction among their technological components. As previously discussed, that choice offers a low-cost solution when compared to Head-mounted display devices. The chosen solution can be used on cell phones and tablets that have a camera. The App code can be compiled for different platforms simply by configuring the Unity compiler. The system is split into two parts: (1) the LVL program analyzer plus translator; and (2) the AR-viewer App. The work aims to create an immersion in

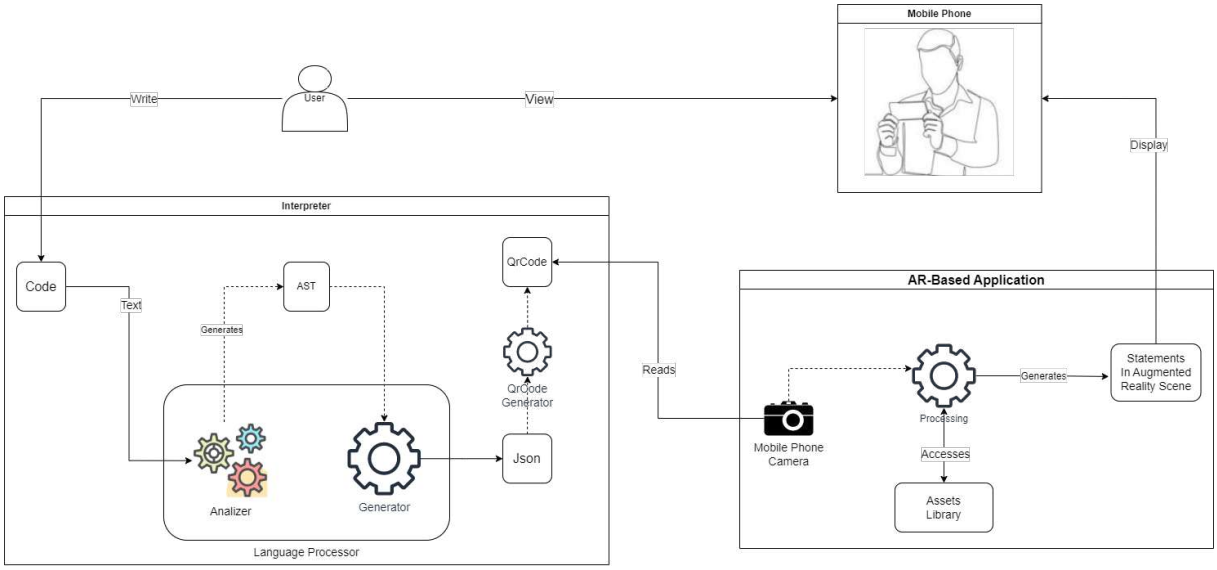


Figure 8.2: Architecture for an AR-based LR to train CT – 1.st proposal

textual programming similar to immersion in the use of virtual systems. In the next section, the complete functioning of the proposed system will be presented.

8.2 LVL Processor

As mentioned above, the overall system is divided into two parts: the input Language Processor (a Translator composed of a lexical-syntactic analyzer plus a code generator); and the AR-based Viewer to display the animation. This section and the next one specify the language and describe its processor. LVL is a simple, imperative (or procedural) programming language, specially designed for this project aimed at supporting the creation of sequential one-dimensional data structures. A parser is capable of transforming the input text (the language sentences) into a syntax tree that synthesizes the meaning of the input program so that the generator can use this information to produce the desired output. After the code is analyzed, the tree is traversed and the information of the input program relevant to the animation (variable declarations and variable manipulations) is extracted and converted to an internal representation in JSON (JavaScript Object Notation) format. After that, the JSON description is then transformed into a QR-Code. In that way, it can be said that the generated QR code contains the input statements in a representation that the AR viewer can understand and recreate. Pointing the camera of the mobile device to the QR-code image, the system is able to collect the information extracted by the processor.

A simple-to-use interface was created to work in a web browser. The user writes the code and presses the button to process the code as in Figure 8.3. With this QR-code, the user points his AR viewer to visualize an animation of his program.

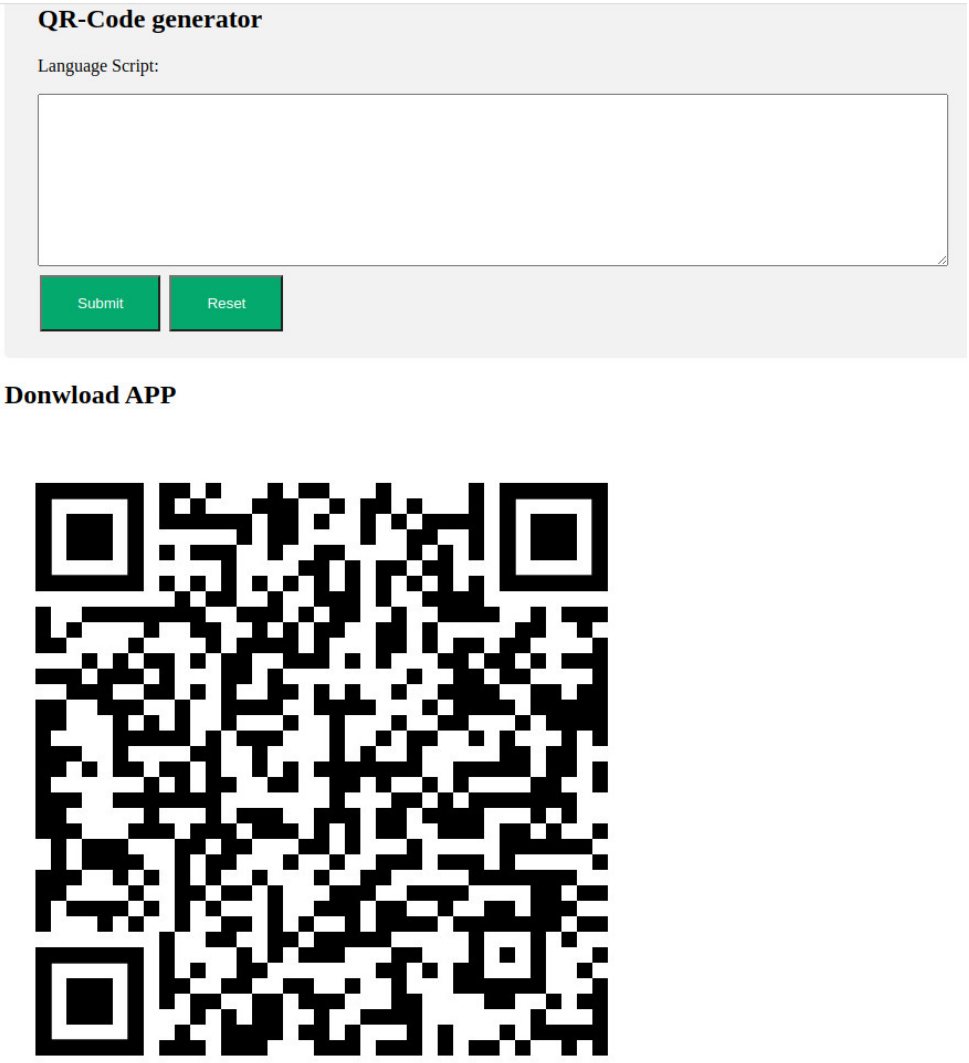


Figure 8.3: Web Interface to analyze a program and transform it into a QR-Code

8.3 LVL Language

At the present moment, the LVL system only supports three data structures—LIST, QUEUE, and STACK—to represent in the program visualization. Of course, variables of atomic data types (integer, real, and string) are also displayed as components of the system state. After declaring the program variables and their respective data types, the language allows the use of statements with special operators to assign them values. For List, the language has the commands `Insert(n)` and `Remove()`. Stacks are based on the LIFO principle (Last In First Out), the element inserted at the last, is the first element to come out of the list. The language provides operators `Push(n)` and `Pop()`. The language also allows the use of Queues. The queues are based on the FIFO (First In First Out) principle, the first element inserted, is the first element to come out of the list. To work with queues, the language provides the operators `Enqueue(n)` and `Dequeue( )`.

Listing 8.1 illustrates a program written in LVL language that declares a variable Stack, and operates with it. Figure 8.4 shows the visual environment produced by the LVL system for the stack code presented in

Listing 8.1. Next, more examples of LVL programs and a description of the AR-Viewer will be provided.

Listing 8.1: Example of a program using a Stack structure

```
1   VARS
2       a, b, c: INT;
3       pilha: STACK(int)
4   STATS
5       a=2;b=4;c=6;
6       pilha.push(2);
7       pilha.push(4);
8       pilha.pop();
9       pilha.push(6)
10  END
```

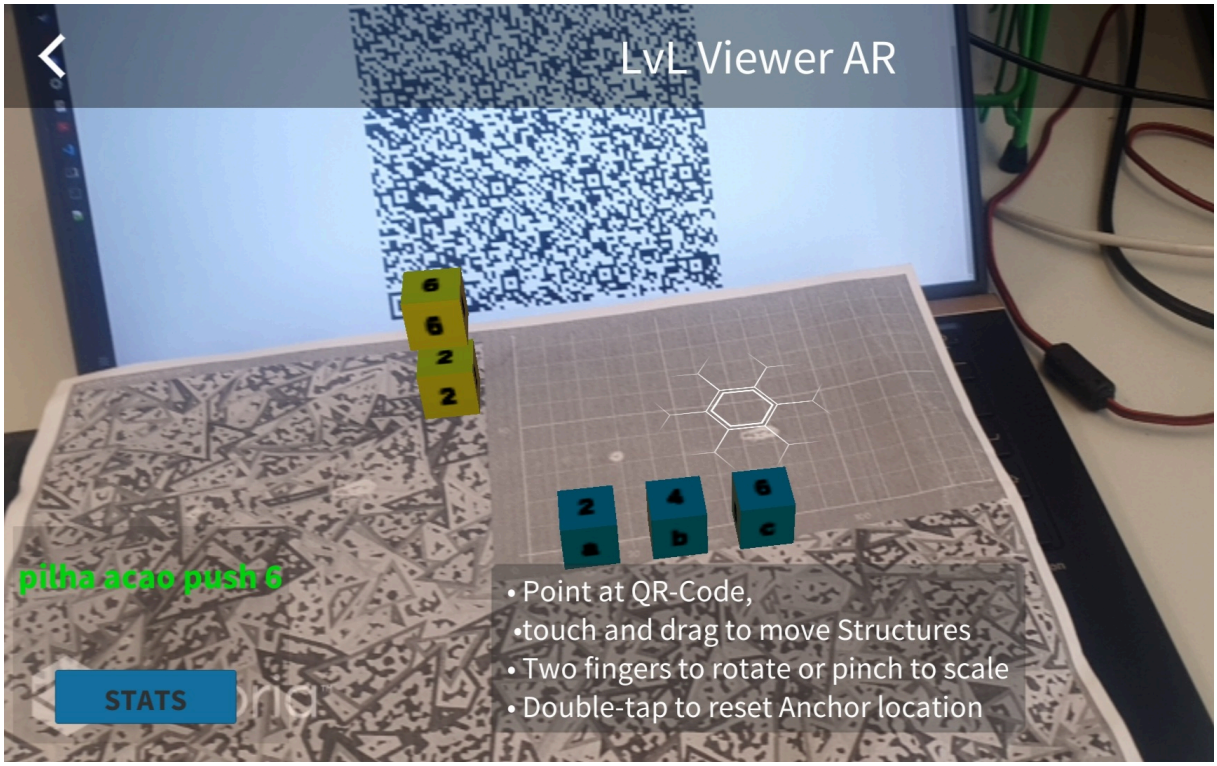


Figure 8.4: Screen capture of LVL animating the Stack program example

8.4 AR-Based Viewer

AR Viewer uses the QR code to read the information processed by the parser. This section describes how the user views the behavior of a program while it is executed. LVL App is very simple to use. First, access the menu to turn on the camera, after which the user points to the generated QR code. The viewer reads the instructions and projects the structures in a colored 3D space. Notice that the animation is triggered without the need for any marker. The system was built to be able to show the effects of each instruction

manipulating the data. Examples of simple programs to operate a List and a Queue are presented in Listings8.2 and 8.3 8.3 respectively, and their visual representations are shown in Figure 8.5 and 8.6.

Listing 8.2: Example of a program using a List

```
1   VARS
2       a, b, c: INT;
3       lista: list(int)
4   STATS
5       a=2; b=4; c=6;
6       lista.insert(2);
7       lista.insert(4);
8       lista.remove();
9       lista.insert(6)
10  END
```

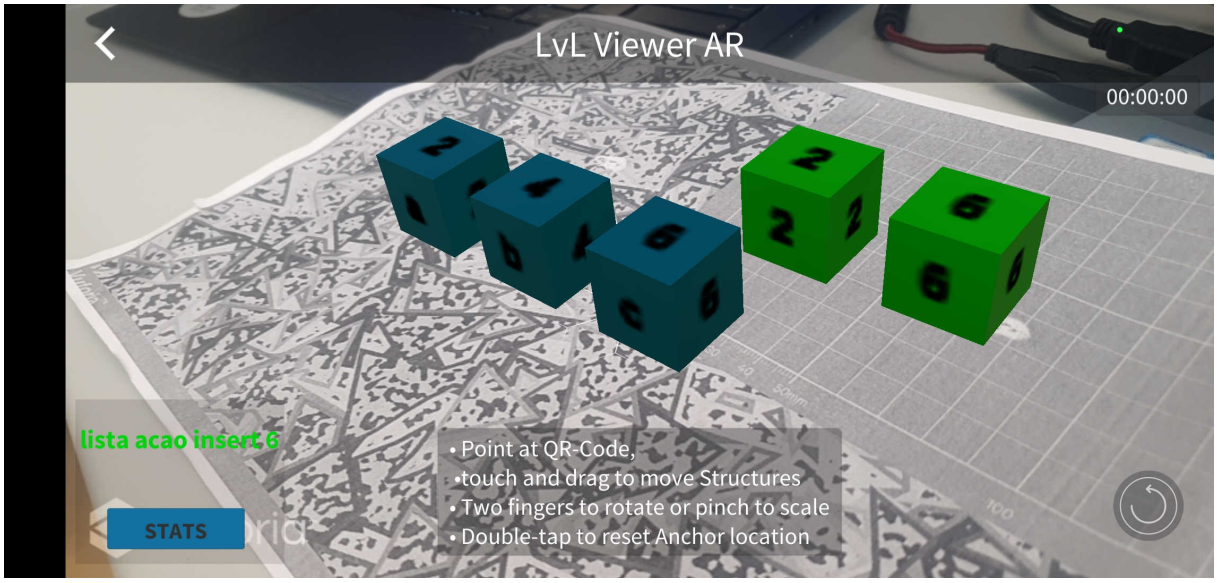


Figure 8.5: Screen capture of LVL animating the List program example

Listing 8.3: Example of a program using a Queue in LVL

```
1   VARS
2       a, b, c: INT;
3       fila: queue(str);
4       pilha: stack(int)
5   STATS
6       a=2; b=4; c=6;
7       pilha.push(5);
8       pilha.push(a);
9       pilha.push(6);
10      fila.enqueue("a");
11      pilha.pop() END
```

Through the screen of the mobile device, the user can touch and navigate through the system statements, observing the transformations that occur in the data structure as a consequence of the operators applied. For more, acess the video link: LVL video link.

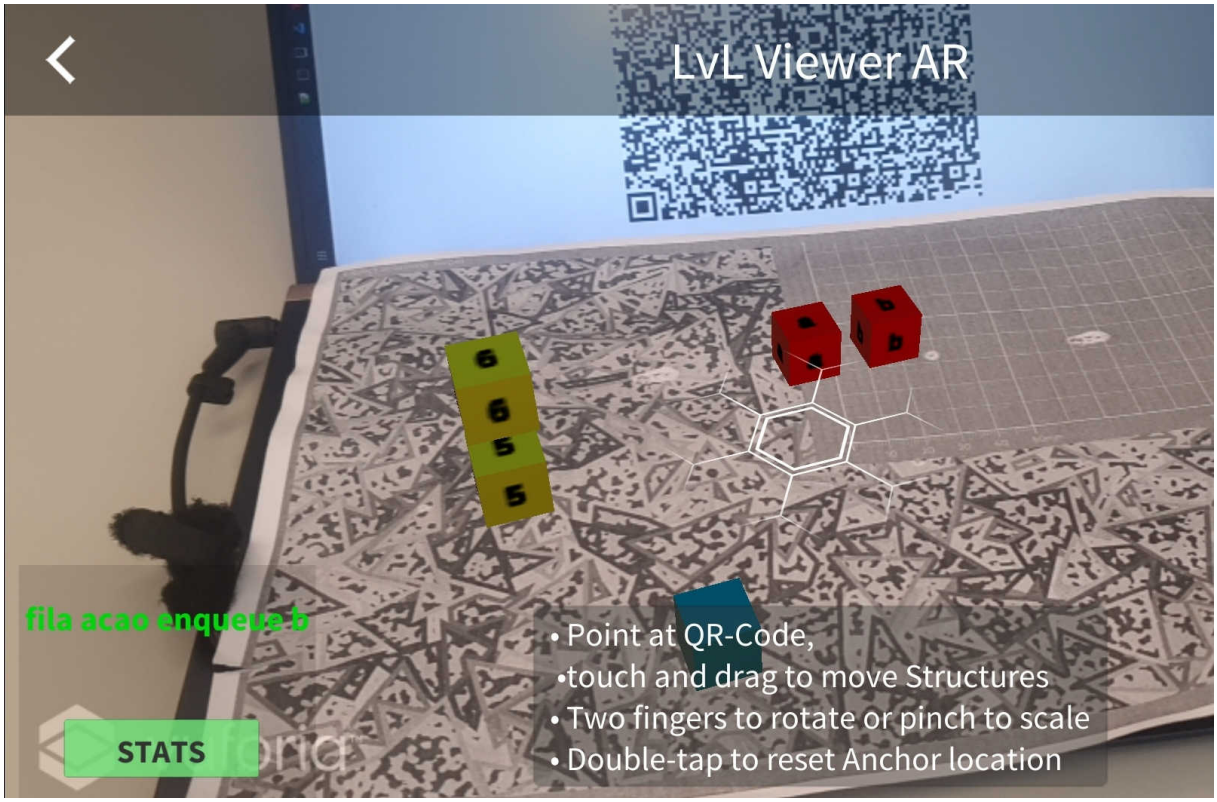


Figure 8.6: Screen capture of LVL animating the Queue program example

8.5 LCSMAR

In this section, is shown the evolution of both the LVL language and processor. LCSMAR, the developed LR, as said before, is divided into two components. The first one, the interpreter, takes the code that the students write in an imperative programming language, interprets it, and generates information that can then be used by the second component to lay-out the execution of the code written in an AR environment.

In order to make these two components more independent from each other, there was a need to find an effective way to transmit information from one component to another, and to do so, the QR Code approach, chosen for LVL, was adopted once again. QR Codes are easy to generate and scan and can be read by almost every modern smartphone. Thus, by using QR Codes there is no need for an internet connection.

LCSMAR was developed in the continuation of the LVL project (introduced in the previous sections) to perform some improvements in the language, either in the processor and mainly in the visualizer, aiming to build a tool easier to use and more engaging and effective. Some of the features of the developed application are, visualizing the written code, advancing or stepping back each line of code, seeing the changes that occur in each variable and data structure, knowing if the current line of code is inside a conditional block, knowing if the condition is either true or false and know if a line is inside a cycle.

To use LCSMAR, users will write their code in a web-browser-based application that is able to generate the QR Code thanks to the information generated by the Interpreter (Figure 8.7).

Listing 8.4: Example of a more complex program using a List in LVL

```
VARS
i,evenSum,oddSum:int;
listOdd,listEven:List(int);
STATS
evenSum = 0;
oddSum = 0;
for (i = 1;i<=10;i++){
    if (i % 2 == 0){
        listEven.insert(i);
    } else {
        listOdd.insert(i);
    }
}
while(listEven.len > 0){
    evenSum += listEven.remove();
    oddSum += listOdd.remove();
}
END
```

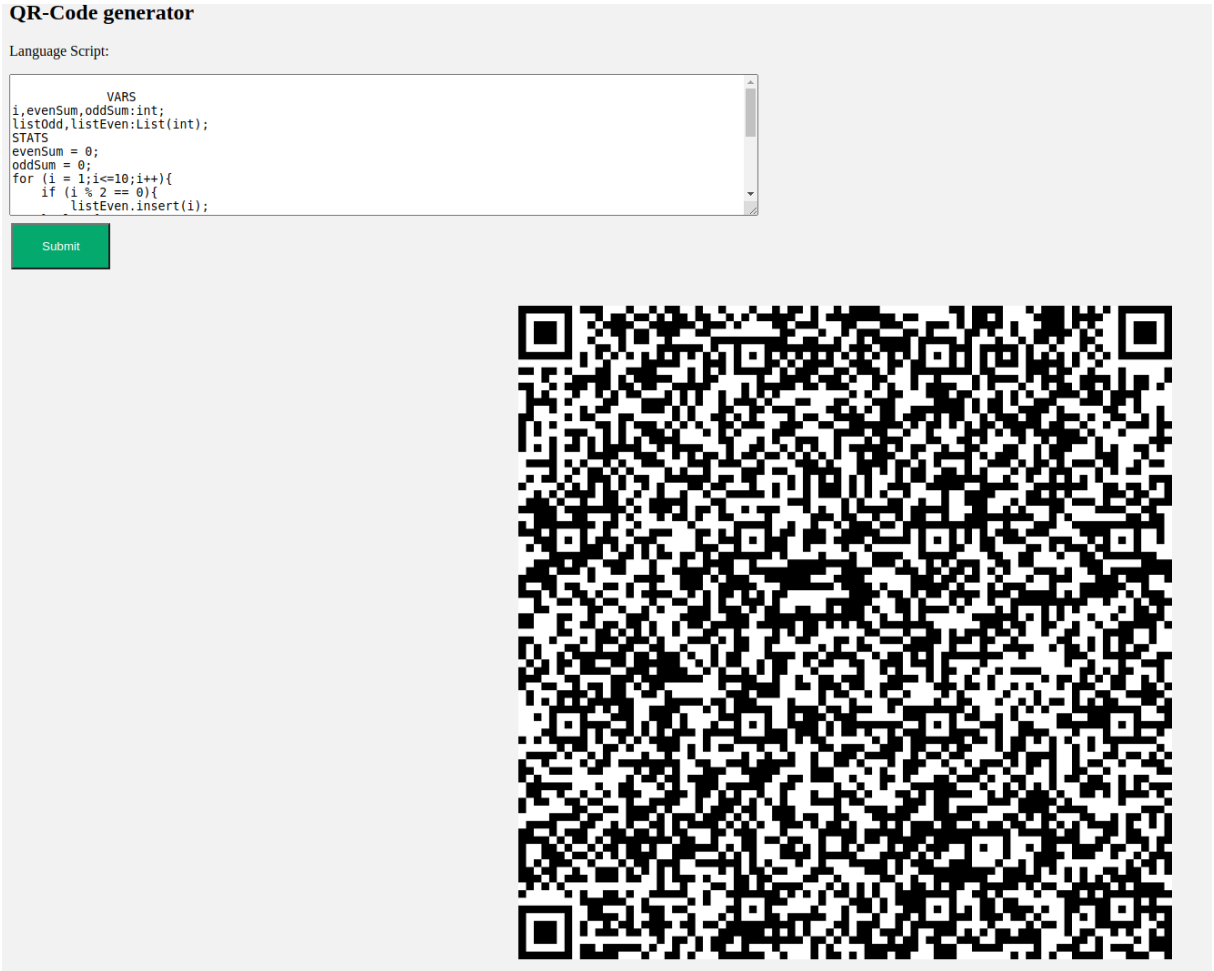


Figure 8.7: LCSMAR Web App where students can write their code

After reading the generated QR Code, the starting scene is generated, exhibiting atomic variables and the empty data structures, which can then change the state step by step using the UI appropriate buttons.

The piece of code in Listing 8.4 will be used to show the features of the AR application. The program inserts the numbers between 1 and 10 in a corresponding List of even or odd numbers, and then it calculates the sum of each, storing these values in their corresponding variable. In Figure 8.8, the variables and their values can be seen represented by the blue cubes displaying their names.

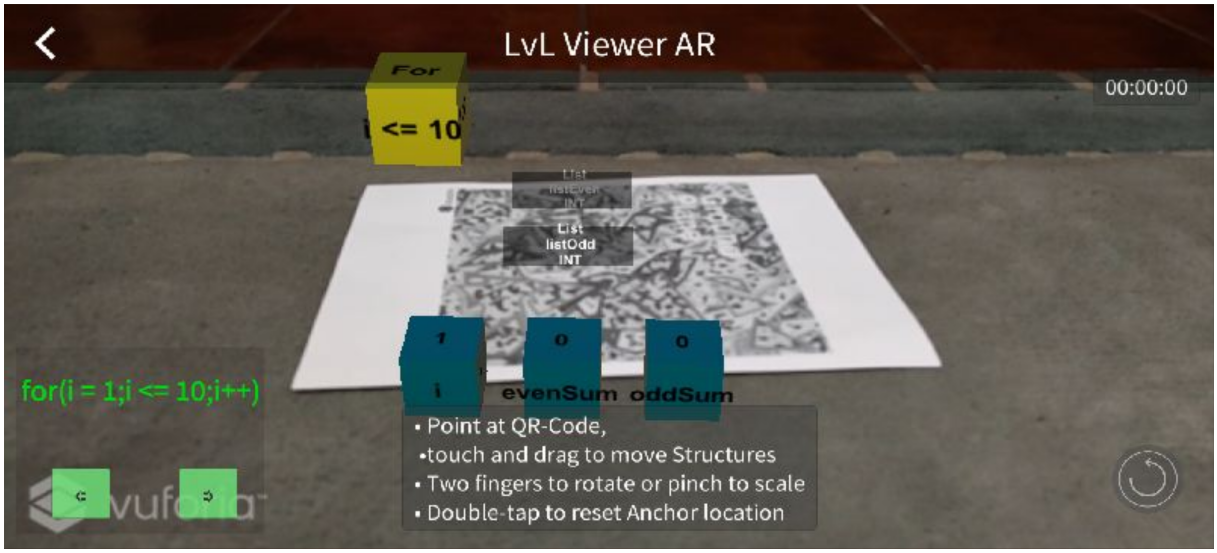


Figure 8.8: Code execution representing a for cycle

When executing a for cycle a new block appears representing it, showing the loop condition. In a similar way a block that represents the if condition can either be red (Figure 8.9) when the condition is false or green if the condition is true.

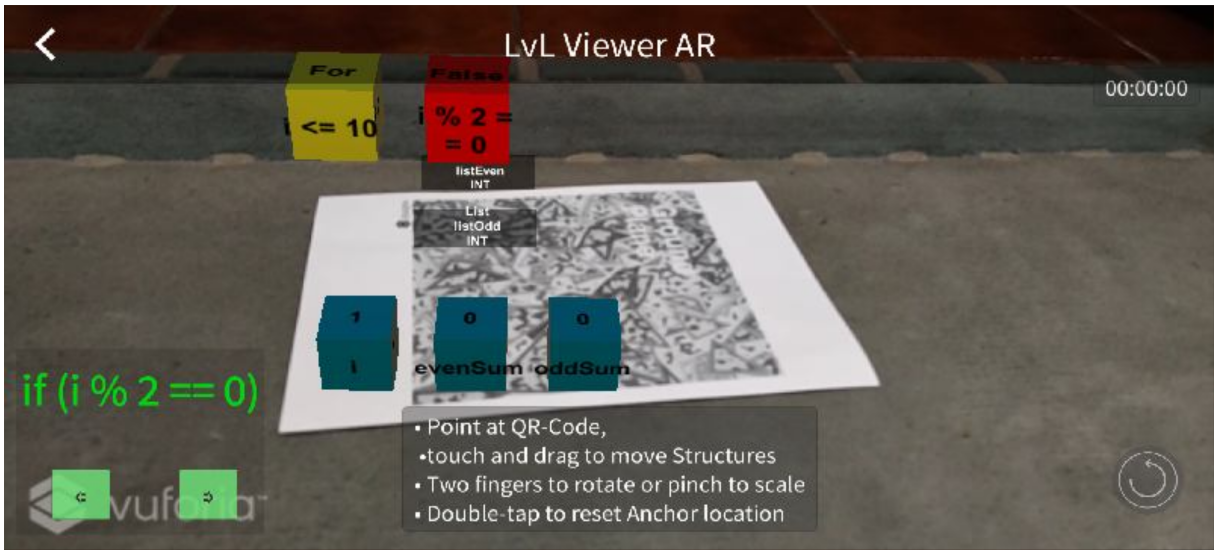


Figure 8.9: Code execution representing an if condition

As the code is executed the content of each data structure changes, adding more blocks, representing each element as can be seen in Figure 8.10.

Then inside a while loop (Figure 8.11) that is represented by another colored block, the elements of each data structure will be removed and then they are added to the respective variable, thus calculating the

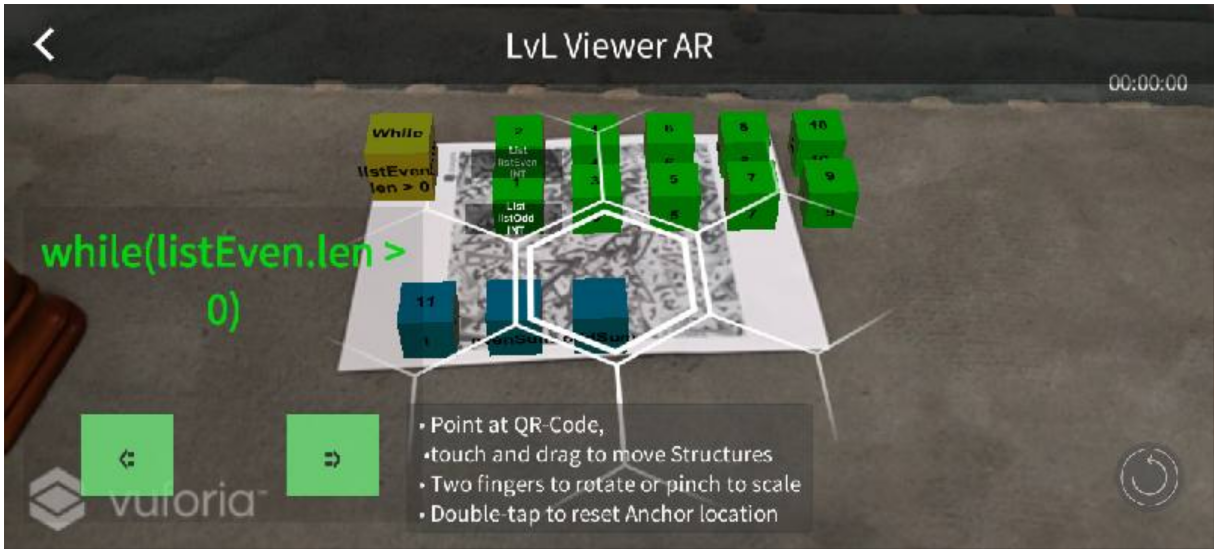


Figure 8.10: Code execution representing the state of the data structures

sum of the numbers.

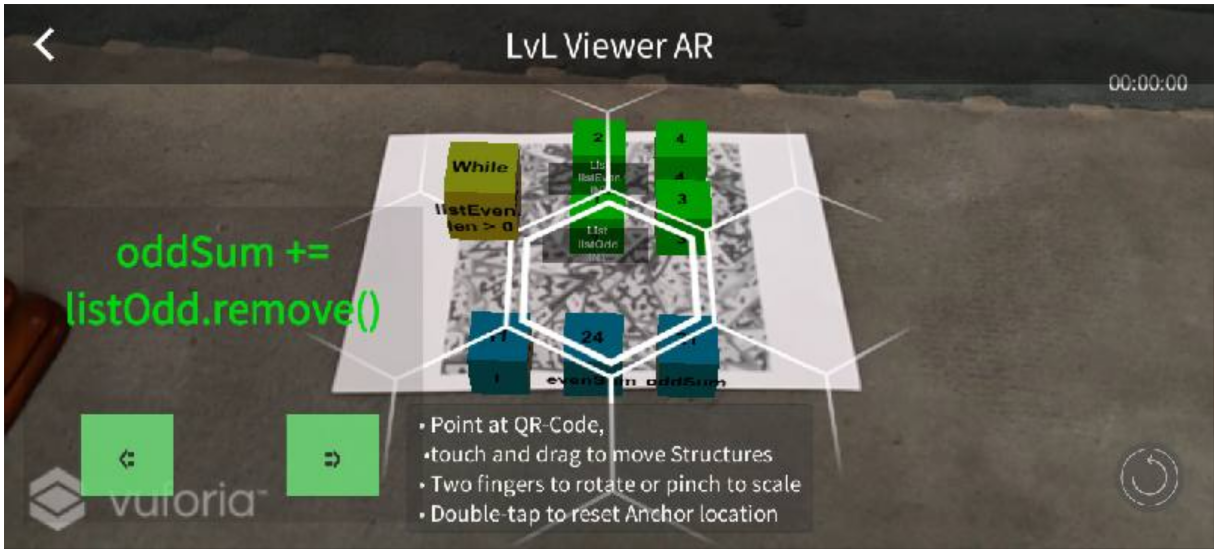


Figure 8.11: Code execution representing the removal of elements from data structures during a while loop

This LR allows students to have a different approach to learning how code works manipulating and changing data structures. By using a variety of teaching methods and tools, such as visual aids, interactive exercises, and real-world examples, students can gain a deeper understanding of the concepts and develop problem-solving skills that they can apply in their future careers. Additionally, a well-designed LR can help students stay engaged and motivated throughout the learning process, which can improve their overall retention and mastery of the material.



Figure 8.12: AR application being used

8.6 Final Discussion

This chapter reported the design and development of an immersive tool (LVL and its evolution LCSMAR) to explore the manipulation of data structures through an imperative programming language. The proposed system is able to represent, in an interactive virtual environment, variables of different types—atomic, lists, stacks, or queues—defining the state of a program. It was demonstrated that this system allows the user to inspect their programs with a mobile device, in order to better absorb concepts related to data structures.

Vuforia library allows for surface recognition removing the need for markers. Taking advantage of the best practices of AR, one can align the objectives of teaching algorithms and data structures with 3D visualization so that the teacher can write a program with declarations and operations and thereafter the students can visualize the effects, this is the program behavior. Similar to some high-level debuggers, the AR-based Viewer shows all declared variables and allows them to evolve step-by-step along the sequence of the program statements, providing a new and attractive environment to understand how statements change the value of the declared structures.

One of the challenges in the development of this project was the question of how to transmit the information extracted from the input program by the Analyzer to the Viewer so that it can render and display it. Initially, wireless data transmission approaches were considered. However, the device's camera is already used for creating the immersive AR scenery making the overall power consumption very high; the device also becomes rapidly to hot. QR-code technology was chosen to overcome this problem.

Another interesting challenge was related to the visual organization of all the objects in the 3D scenario. It was necessary to build specific scripts in Unity to perform the layout of one or many structures of the

supported types aiming at the construction of a nice and clear scenario. With the arrangements made, objects are grouped keeping their relative position in a stable image. Moreover, color mapping is used so that the user can easily identify each data structure. Colored cubes were used to represent data structures.

The ideas and the proof-of-concepts presented and discussed in the work evidence that it is necessary to explore the development of Learning Resources with new technologies such as AR. AR allows total control of the environment. This means that the user can move around the surface of the chosen projection, and pause or repeat all simulations to better visualize the structures. About this AR-based Learning Resource, is possible to corroborate that Augmented Reality allows us to create analogies of simple or complex concepts enhancing their comprehension.

The initial prototype, LVL so far presented, did not support conditional or repetitive control statements; however, its evolution, LCSMAR also introduced above, overcame this flawless and now provides support for the referred control structures allowing to animate more realistic imperative programs. For more, acess the video link: LCSMAR video link.

Chapter 9

Experiment with Students

In this chapter, studies carried out to present the tools to students of different levels of education and different ages will be reported. Experiments were carried out at a Portuguese University and also at the Federal Institute of Technical and Technological Education in Brazil. The experiments that could be conducted in person will be described.

To execute the projects, a combination of computing resources was employed, including both institutional computer labs and personal devices belonging to the students. The computer labs provided access to high-performance machines with specialized software, whereas students were able to work on their projects using their own personal computers from any location with internet connectivity. At the end of that one-hour task, the students answered a questionnaire prepared/designed according to Evaluation of a Mobile Augmented Reality Application (MAREEA), proposed by Pombo et al. (2022) as an Outdoor Learning Tool. Appendix A lists the complete MAREEA form. Four evaluation factors are defined in the MAREEA evaluation model: *Usability, engagement, motivation, and active learning*.

In order to assess the effectiveness and usability of the first artifacts, the experiments were designed and presented to a class of postgraduate students at Universidade do Minho (UMinho, for short). The 12 participants were aged between 22 and 35 years old, including 5 men and 7 women. All participants were teachers investigating new ways to assist them in the activity of teaching informatics.

The profile of the participants in the experiment was adequate due to their specific interest in exploring innovative teaching methods in the field of informatics. The experiments were presented to the class both through video streaming and face-to-face interaction to accommodate all participants.

Following an initial introduction to the functionality of the proposed artifacts, the participants proceeded to engage with the tools provided to complete the activities. Comprehensive guidelines were supplied to

ensure the easy and optimal usage of the games.

Subsequently, after approximately 30 minutes of utilization, the participants were requested to complete a questionnaire designed to evaluate the functionality, behavior, and usability of the proposed games. The questionnaire responses collected indicated that all participants were already well-versed in the usage of AR technology.

With regards to the preference for using a mobile application in lieu of traditional keyboard and mouse input, the feedback was resoundingly positive. Nevertheless, some participants also expressed interest in hybridizing both input methodologies.

Regarding the use of Make Your Hero game, all participants found the task to be facile to use, with the majority providing favorable feedback on the ability to customize a character with specified attributes. Furthermore, all participants demonstrated an astute comprehension of how to manipulate the cards and interaction buttons on the interface.

About Shrews game, the answers showed that the participants understood the three levels of difficulty and asked for more challenges. Of the participants, 50% said they would like to use this type of tool to train their students on the concepts related to CT, but there are still 25% with no definitive answer. 50% out of the Participants would like to have the app installed on their mobile phones; everyone would recommend it to friends. For instance, one of the Participants said: "The interface is intuitive, the project is interesting. There are infinite possibilities for applying the project in the classroom. Congratulations!".



Figure 9.1: Participants experimenting AR projects.

The pandemic created by the SARS-CoV-2 virus has converted many classes into online classes. However,

the experiment prepared can still be performed in this situation and can be done by students at home.

Following the initial presentation and feedback gathering, illustrated in the photo of Figure9.1, the subsequent experiment was carried out with adolescents, and its findings will be presented subsequently.

9.1 Make Hero Experiments

For each experiment, a different number of responses was obtained, as the questionnaires were answered voluntarily.

The experiment involved two high school classes consisting of a total of 31 students aged between 14 and 16, including 12 girls and 29 boys. 18 students from class A (12 males and 6 females) and 13 from class B (7 males and 6 females) answered the questionnaire.

The presentation was conducted in the morning during the first class, and while some students initially appeared sleepy during the introduction of the concepts, their interest was sparked once they were presented with the instructions and images of the activities. The students were excited to engage in an activity that was different from their regular classroom routine. It's worth noting that the participants were students who were beginners in Computer Programming and were enrolled in the Computer Technician course.

After the presentation of concepts related to Computational Thinking and how AR-based LR works, the other teacher was observing and recorded information from the experiment. Then a link was shared to download the game. The system was developed for a younger audience, but the objective is to test the motivation and its usability. In Figure 9.2 the motivation of students to explore the Learning Resource is clearly visible.

To solve some device compatibility issues, students were advised to try it in pairs. A period of 15 minutes was made available for students to use after installation so that teachers could observe if the instructions for use were absorbed by the students. After this initial period, the teachers moved to personally meet each group of students to carry out two proposed activities. Some students could not install it because there was a parental control system or their device was of a brand incompatible with the system. Figure9.3, shows the sequence of completed tasks. The first activity was to create a custom character and make a note of the chosen characteristics. The second activity aimed to create a hero with characteristics passed on so that everyone could create the same character. At the end of the time to experiment and carry out the two activities, the students were given the questionnaire proposed by Pombo et al. (2022), as explained above. Students were motivated by the technology and way of operating the Learning Resource.

At this school, there is no separation of students with special needs. It happens that in the 2 classes tested, there were reports of 5 students with autistic spectrum. Gratefully it was noticed that one of the students with Autism Spectrum interacted very motivated with the game, and created the custom characters. After that, the student took the interaction cards home to show more personalized characters.

Following the utilization of the Make Your Hero game, a questionnaire was subsequently administered to evaluate the system, resulting in feedback from 31 respondents.



Figure 9.2: The image shows the engagement of all students in the activity

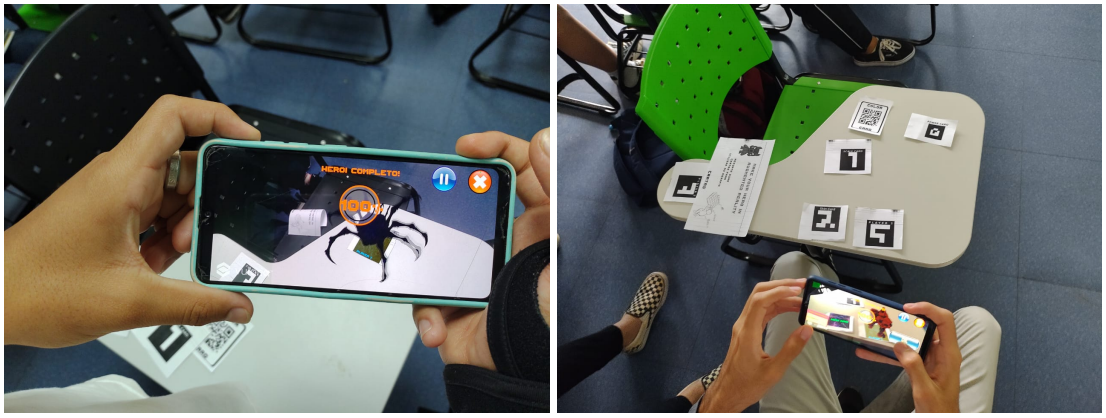


Figure 9.3: the image shows that after a few minutes, the students had the task completed

9.1.1 Discussion and Conclusions

Graphs generated from student responses indicate positive feedback towards the system. Taking into account the ”agree”and ”totally agree”responses as positive, there was a total of 74.2% of students who found it easy to learn how to use the app(see in Figure 9.4).

Ten responses were highlighted in both positive and negative reviews. A couple of students realized what the activity was for and enjoyed trying Augmented Reality with the answer: ”It’s a great way for you to experience VR.””I thought the app was cool, but it was hard to use on old cell phones.””Liked because of

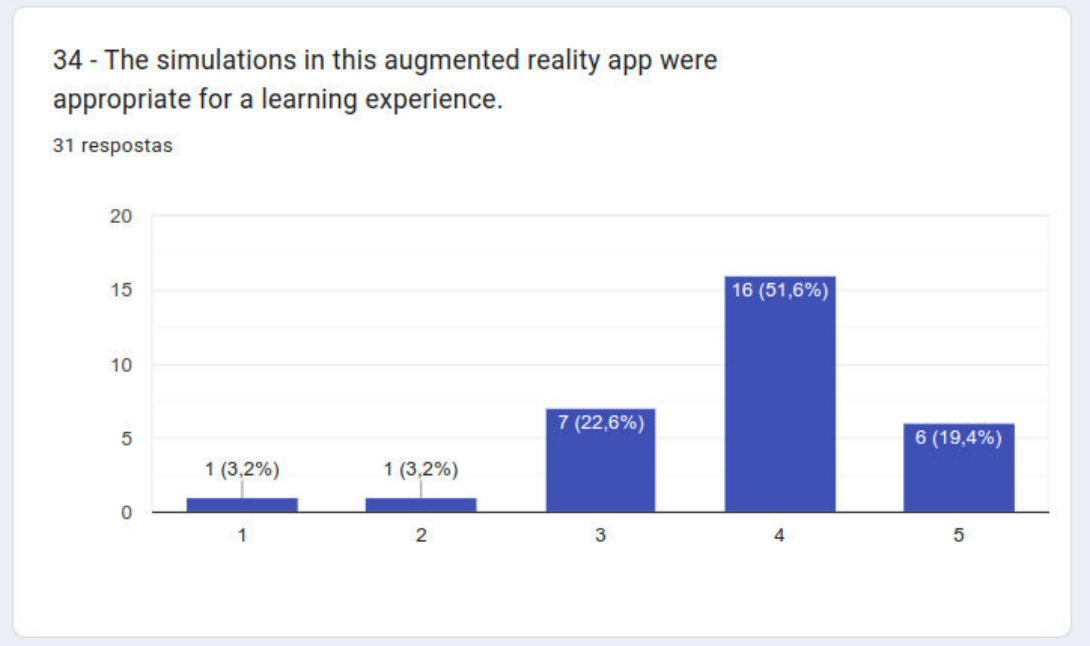


Figure 9.4: Question about AR app for appropriate learning experience

the different characters, but had difficulty using the cards."

One student suggested "Better information in the interface", showing that not all information was clear in the system. There were totally positive comments like: "Everything, I love it!!"and "I liked Everything in the APP". Some students have reported system errors as seen in the following responses: "Could have a more practical access and have a better way to access the QR-codes"or with the answer "the letters were not Focused on the cell phone"; "Difficulty opening stored character". Two responses stood out in the constructive criticism, as teenage students understand design and human-machine interface: "The font color (yellow) besides being tiring, it didn't look good visually. I loved the game, I would like to interact with my friends' heroes."

There were suggestions for future work on creating an online combat arena in which there would be a battle with the custom characters.

Appendix B is a full listing of the graphs depicting the students' answers to all the question.

9.2 Shrews Experiments

AR-based learning resources were introduced to the two classes that tested the 'Shrews' app. A total of 42 students used the system, 26 males and 16 females. Observing Figure 9.6 it is possible to confirm the motivation of students using App Shrews. 27 students from class A (19 males and 8 females) and 15 (7 males and 8 females) from class B answered the questionnaire. The experiment was conducted following the format of previous experiments. Subsequently, a download link for the activity was shared. Although the system was designed for a younger audience, the objective was to evaluate the motivation and usability of the game. Figure 9.7 shows students interacting with the AR-based Learning Resource

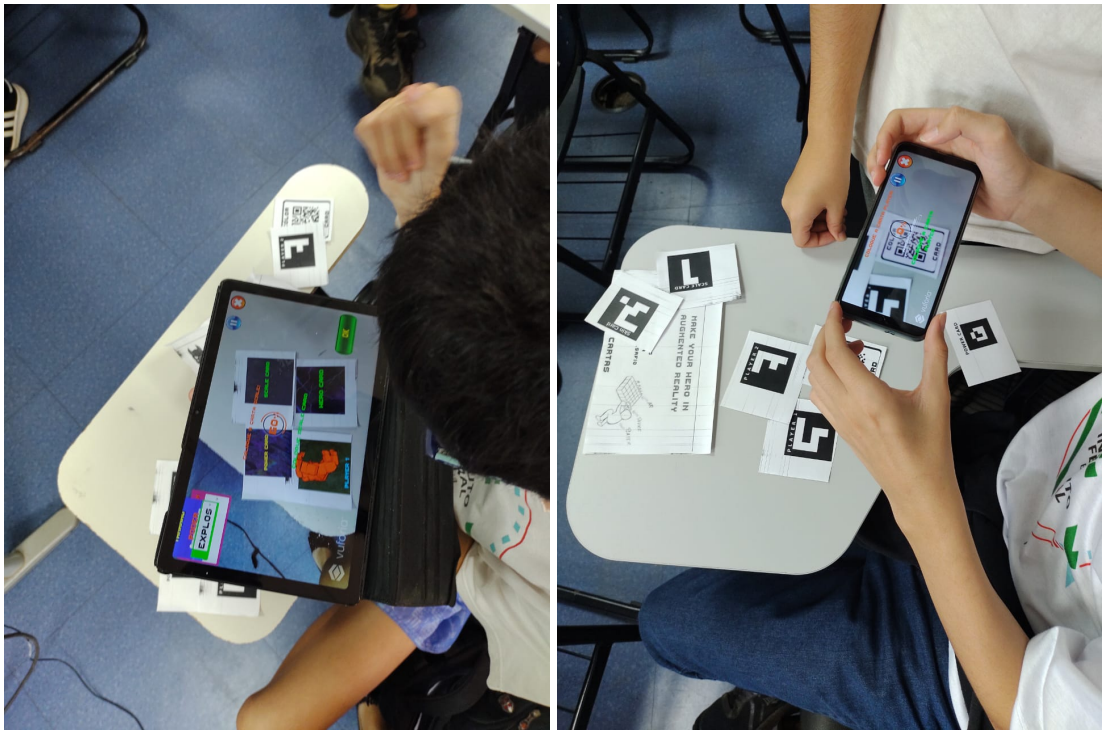


Figure 9.5: Students in experiment in classroom



Figure 9.6: Participants experimenting at Shrews AR project.

A time of 15 minutes was made available for students to use after installation so that teachers could observe if the instructions for use were absorbed by the students. After this initial period, the teachers moved to personally meet each group of students to carry out two proposed activities. Figure 9.8 shows



Figure 9.7: Participants experimenting AR projects.

students interacting with virtual buttons in Augmented Reality.



Figure 9.8: Participants experimenting Shrews AR project.

9.2.1 Discussion and Results

All the participants enjoyed using and carrying out *Shrews* activities. There was a report of difficulty in handling the cards, as the student had difficulty focusing the cards in the camera's field of view. The results indicate a good experience identified by students shown in Figure 9.9, Figure 9.10, and Figure 9.11.

It is interesting to report that 61% of students responded that the experience was rewarding, which is equivalent to the 59.5% positive feedback received from those who were interested in using the app.

The students found the AR app easy to use, but they reported that the system allows for mistakes. Regarding the interface, it is clear that the students suggested changes, with 42.9% approval.

Appendix C is a full listing of the graphs depicting the students' answers to all the question.

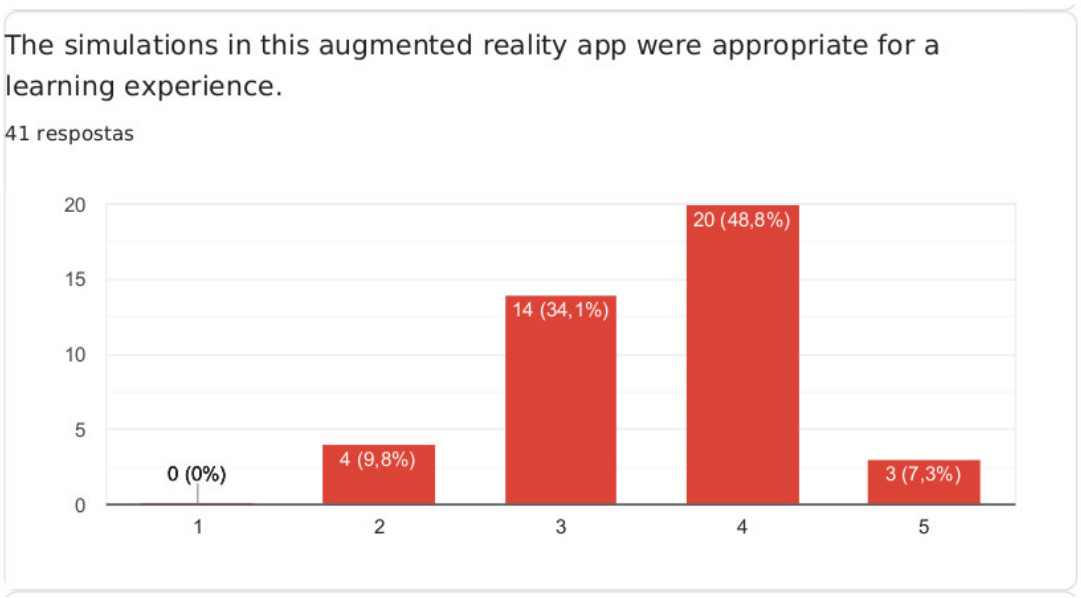


Figure 9.9: The result of question about Learning Experience

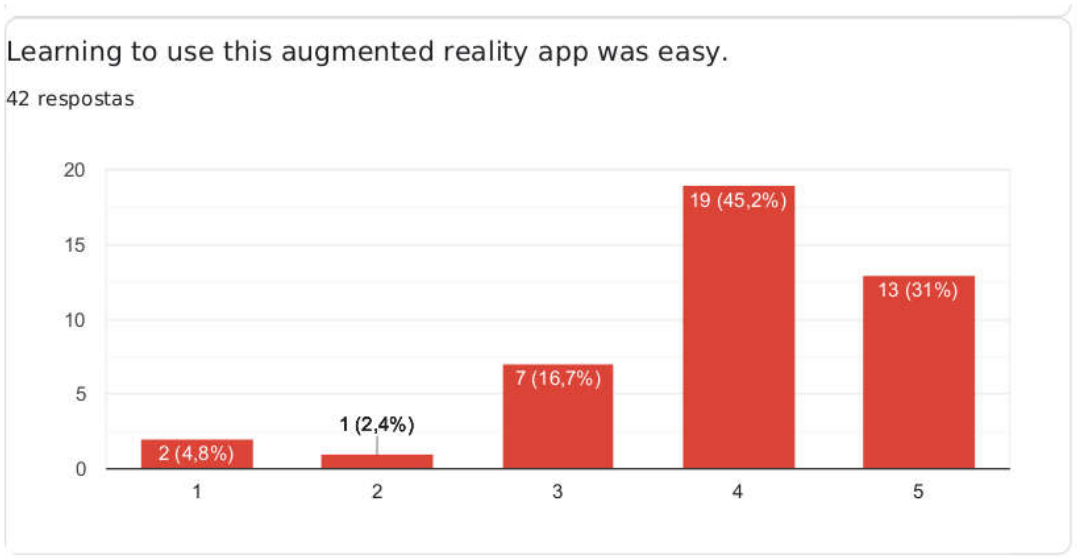


Figure 9.10: Result of usability test

9.3 LVL Experiments

To validate the LVL tool created, an experiment in a real classroom was conducted. That experiment took place with a group of students graduating in the IT course at the University in Brasilia. A total of 7 male students participated in the experiment, aged between 20 and 24 years old. The presentation was carried out in the classroom. After introducing the Language LVL, a link was shared to download LVL. There were two exercises for students to test their knowledge in the LVL language and the visualization of the script in the AR app. The exercises were as follows:

1 - A company is organizing a systematic way to present its products using augmented reality solutions. The presentation order will be: 1.st - "Intro"; 2.nd - "History"; 3.rd - "Staff"; 4.th - "Structure"; 5.th - "Thanks".

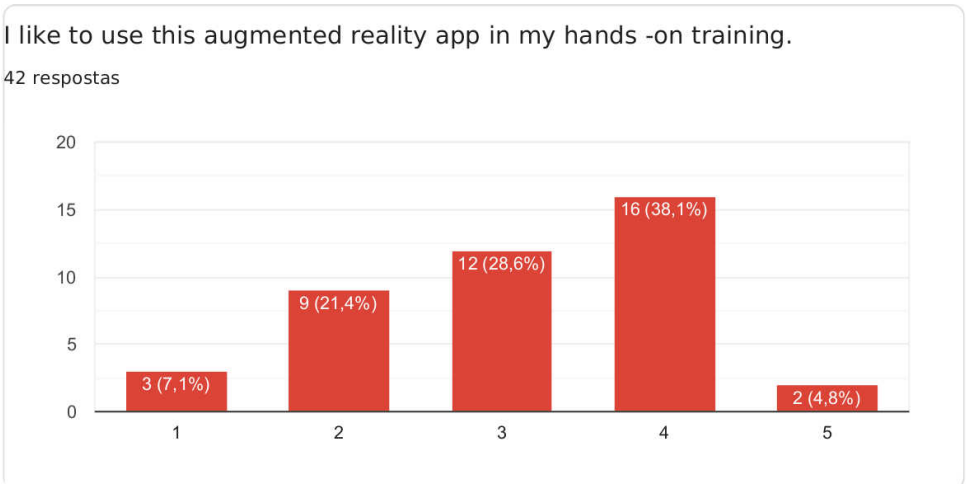


Figure 9.11: I like to use this augmented reality app in my hands-on training

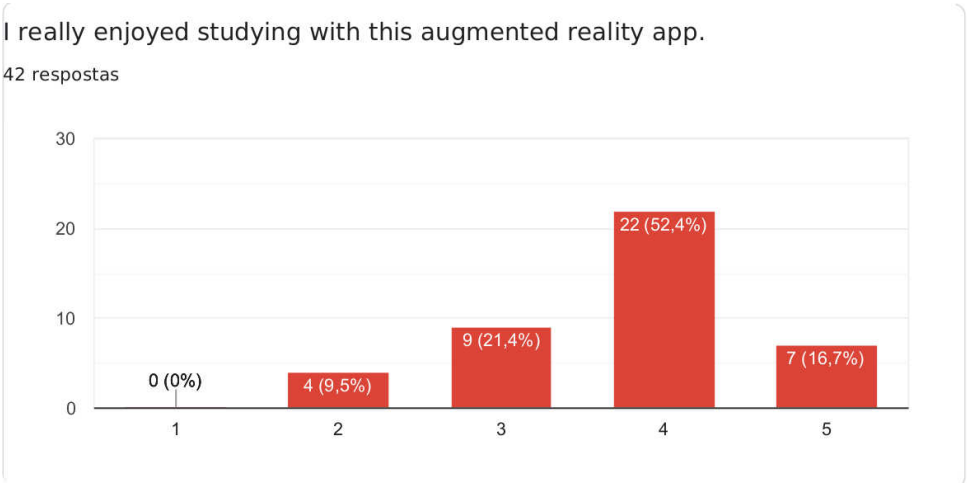


Figure 9.12: I really enjoyed studying with this AR app.

Using the LVL language, students created a script describing the three different structures available LVL (List, Stack, and Queue).

In the second part, students modified the same script to remove four elements from each structure created.

After writing and testing the scripts, seven students uploaded their assignments to a virtual learning environment.

To carry out the activity, the students spent an hour writing the script and compiling it with the LVL processor available online.

All students were able to successfully complete the activities. Student feedback indicates that all students agree with the statements contained in the MAREEA questionnaire. In the open question, one student wrote that the system was "Good for Learning". Corroborating with the thesis that an Augmented Reality tool can help in understanding complex problems. The experiment had good feedback showing that all students were able to understand the language and manipulate the visualization tool. Interface improvements were suggested to improve the visualization of subtitles in structures. It is necessary to expand the experiments with a more significant number of students. In the subsequent section, we will be presenting the utilization

of the AR-based Learning Resource that visually represents a script created by the student.

9.4 Findings and suggestions

The pandemic caused by the SARS-CoV-2 virus has forced many classes to become remote, with students learning from home. While this type of learning is still viable and can be done by students online, the lack of face-to-face interaction and the inability to collaborate and exchange characters with classmates can make the task less motivating. This situation highlights the importance of finding ways to maintain social interactions and collaboration among students even in a remote learning environment.

Part III

AR-Based resources Development Generalization

Chapter 10

Development of AR-based Resources

As discussed in the chapters in Part II, it was necessary to evolve and improve digital technologies, in order to build sensitive learning resources that could be applied in the basic education curriculum. These resources would train students in the basic principles of CT and, as a consequence, enable them to correctly solve problems using computers. In this context, it was researched the inclusion of Augmented Reality components in some devices to create new and improved LRs. Along this Ph.D. work different kinds of resources were created in order to improve skills related to CT and problem-solving, as illustrated in Figure 3.6. The different approaches so far explored include (1) AR-based learning resources to introduce strategies for problem-solving, (2) AR-based learning resources to train CT skills, and (3) AR-based resources to support direct problem-solving in computer programming.

10.1 AR-based Learning Resources

To learn computer programming, it is important not just to focus on coding but also to analyze problems, design solutions, and test and optimize them. CT helps express how to solve a problem and involves concepts such as decomposition, abstraction, and algorithmic design. CT is crucial for computer programming, and learning resources play a vital role in training CT. The more comprehensive and informative the learning resources are, the more effective they become in facilitating the training process.

In regards to whether or not a learning resource developed with AR technology impacts CT training, it can be argued that an AR-based resource can have a positive impact. AR technology offers a 3D view of the problem and allows for the visualization of complex analogies and abstractions, which can enhance the CT training experience, aiding in understanding complicated programming concepts. A conceptual definition

stage was completed via formal description using *OntoCnE*, providing a roadmap for the exploration of CT. The chief objective of this project was to create tools that could train CT skills. To attain that purpose, it was:

- Studied the area of AR in Education in a wide and deep way to characterize and classify these tools to better understand what AR is. In that context, the systems that were proposed and developed were identified, as well as, which approaches were used in their implementation and what was resolved, and what deserves further research;
- Created a generic architecture that can always be adopted to build an AR-based LR (shown in Figure 8.2).
- Identified which components are stable and which vary from one given system to another, and understanding what information needed to be specified in each case;
- Used *OntoCnE* to guide the exploration of the CT abilities;
- Developed a processor to parse programs written in a formal programming language and promote its visualization in an AR-based Learning Resource;
- Validated the proposed approach and the developed Learning Resources with experiments.

Starting from the same basis—the relationships among CT concepts and Computer Programming clarified and formalized through OntoCnE— different interfaces for the creation of AR systems were carefully explored aiming to improve educational tools to train skills related to CT. The LR requirements were developed in a participatory way with the users.

The curricular component described in Section 10.2 was created to develop more projects that result in AR-based Learning Resources. It is emphasized that the steps outlined here for creating LR with AR-based are always followed in projects finished (shown in Figure 10.1). The next sections propose strategies to develop Learning Resources based on Augmented Reality.

10.1.1 Introduction of CT concepts

In this section, are shown the strategies to develop LR to support different types of CT training approaches, namely for introducing CT, training CT, and using and improving related skills. To effectively teach CT, it is important to group learners by age and tailor the introduction of concepts accordingly. Once the basics have been introduced, training in computational skills can include exposure to various programming paradigms and languages that handle complex data. Recommendations for such training can be found in the OCDE (OCDE, 2017) and World Economic Forum (Forum, 2016). These documents provide guidance for creating effective training materials for developing CT abilities as well as for supporting introductory

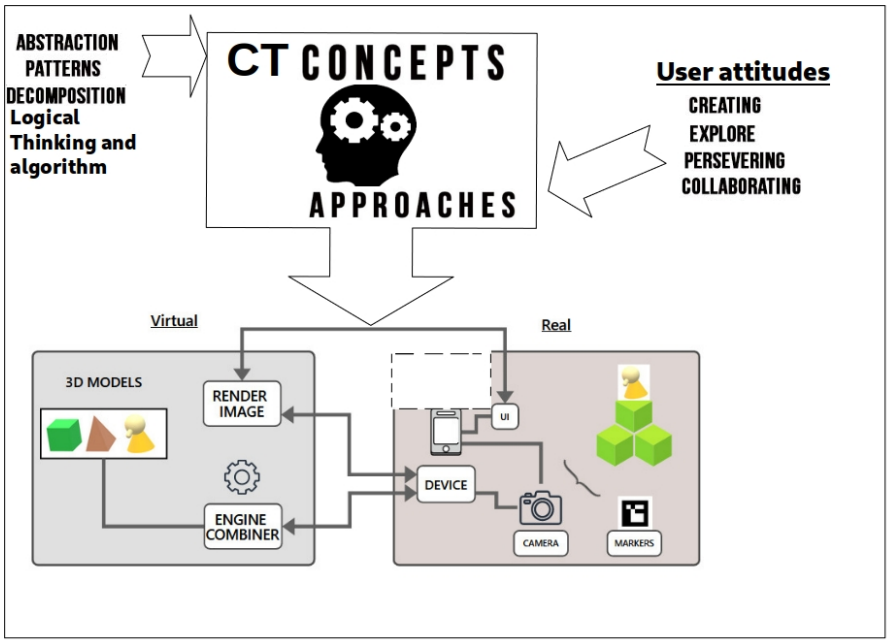


Figure 10.1: Architecture explored in the development of Learning Resources

courses on Computer Programming. For each of the approaches, there is a target audience for the type of Learning Resource based on Augmented Reality.

Introduction to computational thinking with AR-based resources in early learning ages (childhood) using various types of markers such as printed, hand-held, and building cards as a suggestion. It is recommended that children develop certain skills in information technology, such as creating low-complexity algorithms to solve specific challenges and problems and using activities that involve creating flowcharts with a sequence of actions. Interdisciplinary themes can be presented with CT approaches as seen in Figure 10.2. Additionally, children should be able to distinguish the features, functionality, and applica-

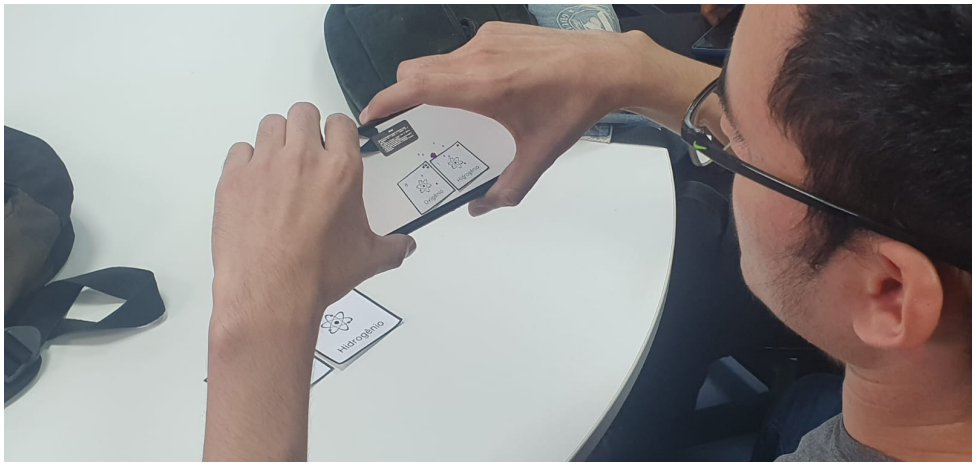


Figure 10.2: Periodic table in Augmented Reality

bility of different tangible objects and use them to solve challenges by programming tangible objects and using marker letters and characters in 3D scenarios. In this scenario, it is proposed the design of digital artifacts for the presentation of narratives, such as music and video, as well as the creation of algorithms and/or programs that involve the interaction with virtual or tangible objects to create simple games. For non-reading children, audio guide instructions, colored fonts, and interaction and comparison between activities are recommended. Support for stabilizing equipment used for AR is also suggested.

10.1.2 Creating LRs and Training CP

To train programming students who already have been prepared and introduced to CT, it is recommended that students develop skills and competence that allow them to understand and use elementary techniques of capture and image editing, sound, video, and 3D modeling. They should also be able to explore modeling tools for creating VR and AR characters and environments. With this type of technology and approach, students will learn how to use the potential of applications for the digital representation of data and statistics. They will also be able to explore the concepts of “Internet of Things” and other emerging technologies such as Virtual Reality, Augmented Reality, and artificial intelligence. Using AR-based resources on mobile devices allows students to learn and explore new ways of interacting with digital devices. Introducing how AR works promotes strategies that involve students’ creativity for the future creation of applications for mobile devices, using appropriate design and development methodologies. One approach to motivate students is gamification. AR allows the use of ”virtual buttons”to interact with the 3D puzzle scenario. This allows for user interaction through the printed marker. Exploring the challenge completion strategy makes algorithm training and solution building more interesting.

10.1.3 AR-based LR for practice CP

The use of AR-based resources is employed to practice computational thinking and understand complex concepts such as data structures, programming paradigms, and visual representations of abstraction. These resources are intended for advanced students with some experience in programming languages and are utilized by undergraduate and graduate students. As the students are older and already have a high level of knowledge, their understanding of the tasks and concepts applied is greater. Figure 10.3 shows the use of a mobile device to utilize the Learning Feature. The concepts of computing itself can be difficult for students to learn, such as computing paradigms or even subjects such as data structures or the operation of algorithms. Examples of activities that can help students understand these concepts include hands-on activities such as cabling and data transmission in networks, server programming, and guided tutoring. Learning resources can also be exploited, such as tutorials and different ways of presenting complex concepts. This can include tutorials for configuring tools for undergraduate students.



Figure 10.3: LCSMAR, An AR-based tool to inspect imperative programs

10.2 Developing AR-based Learning Resources in a Curriculum component

AR technology can provide animation, sound, and video to make traditional resources more engaging and effective in transmitting information. One way to utilize this technology in education is to develop a course that introduces the concepts of Virtual and Augmented Reality Systems. After the introduction, the course could explore different types of systems created with each technology.

The content of this course would include an introduction to Virtual and Augmented Reality Systems, presenting the history and evolution of VR and AR systems, equipment, and different types of interactions. The course would also focus on the design of VR and AR systems using the principles of CT to approach and train related skills. The process would be guided by *OntoCnE*, the already referred ontology for CT, to provide a formal representation of the knowledge domain for adequate resources. The course would also cover AR-based LR type classification. This study covered the concepts necessary for successfully developing AR-based resources. After understanding the concepts related to the CT, the students developed themes according to these concepts. Producing AR-based LR was a challenging and exciting task, but it could be very time-consuming if done manually.

After understanding concepts related to CT and Augmented Reality, students were able to develop their own AR-based learning resources. To get the most out of CT skills, LRs must be attractive, motivating, and effective.

The initially proposed projects were intended to be completed separately. However, students formed pairs

to work on the projects. As a result, they developed five of the projects together in this first class of the course. The course "Introduction to Virtual and Augmented Systems"has been in progress for three semesters. At the end of the semester, for assessment five projects were presented with live demonstrations accompanied by the respective development report. In the first occurrence of the referred course, the five projects assessed were:

- Battle in AR;
- Assistance in learning multiplication tables with AR;
- Social network filter using AR and Meta Spark;
- "What animal is this?";
- Solar System in Augmented Reality.

In the second occurrence of the course, five projects were suggested and prototyped by the students. They are as follows:

- Memory Game in Augmented Reality
- Periodic Table in AR
- States of Water in AR
- Basic Biology in AR
- Biology for Children in AR

Some students did not complete the project due to dropping out of the study component, while others joined ongoing projects to form pairs for the final presentation. During the presentation, all application projects were displayed with live demonstrations. A project development report was also required as part of the evaluation.

Additionally, an image of the working screen for each project was also presented.

The unique aspect of this learning resource was the use of gamification. As shown in Figure 10.4, the Battle System in Augmented Reality was one of the projects. The characters would only engage in battle if the cards were close enough. In the project shown in Figure 10.5, the student created a math competition activity using AR technology. The system, developed using AR.js, presents a mathematical operation along with two answers displayed on markers. The player must cover one marker to select an answer and the answer will be evaluated. There is a time limit for answering all questions and a final score is displayed at the end.



Figure 10.4: Screen of Battle in AR



Figure 10.5: Math operations with AR



Figure 10.6: Solar AR system - Unity 3-D® with vuforia

In the project presented in Figure 10.6, the student created a 3D representation of the solar system with moving planets. The user can explore the various planets and learn about their characteristics. The student utilized Unity 3-D® technologies with the Vuforia library to create this project.

As for the project displayed in Figure 10.7, the student used the Meta Spark tool and facial recognition technology to create a filter for social networks with head movement-based interaction. The user tilts their head right or left to answer a question displayed on the screen.

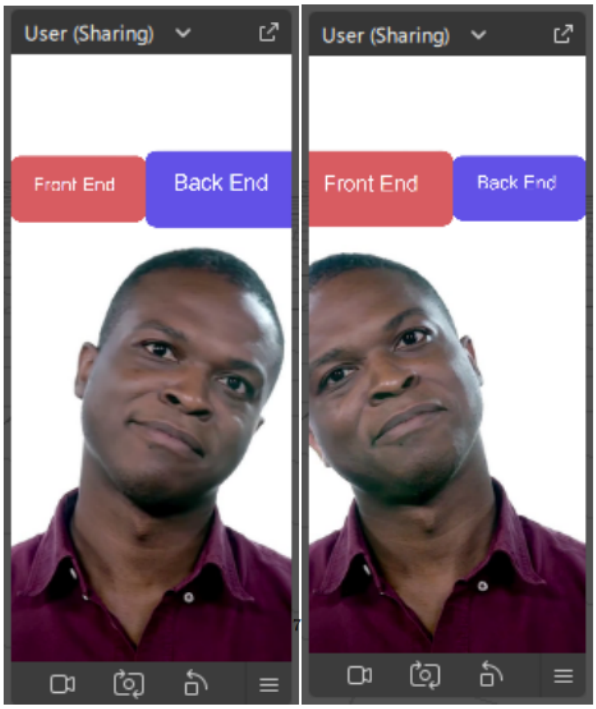


Figure 10.7: Filter for Social Networking in AR

During a single semester, students gained a thorough understanding of the concepts associated with CT and practiced with multiple AR technologies.

Chapter 11

Conclusion and discussion

Coding is important, but not enough to learn Computer Programming (CP); It is also necessary to learn how to analyze a problem, to strategically plan how to design a solution schema, test and assess outcomes in order to optimize solutions. In other words, to establish an immersible and stimulating learning environment to acquire problem-solving abilities, it is important that the Learner engages in the formulation of hypotheses, strategic planning, and experimental problem-solving.

To teach all those fundamental skills to become a Programmer, as argued along the dissertation, *smart choices* must be made to create adequate Learning Resources (LR) that help young people to train their abilities in Computational Thinking (CT). *Smart choices*, in this context, means many things. In some situations, a smart choice can be the use of unplugged games (with paper and pencil, or other physical stuff) involving one or more disciplines. However, in other cases, an opposite smart choice can be the resort to modern digital technologies. It is important to keep in mind that new technologies must serve as facilitators for accessing information and knowledge, while also addressing the inequalities created for those who lack mastery of such technologies.

Namely, Augmented Reality (AR) technology can provide multimedia to make traditional resources more appealing, and more helpful in transmitting information. So, in the context of this doctoral project, it was investigated the inclusion of Augmented Reality components in some devices to create new, improved, Learning Resources. The research done covered to main objectives: the development of LR to train CT; and the development of LR to aid novice Programmers in their path to learn and understand algorithms and data structures.

OntoCnE, an ontology that provides a formal representation of both knowledge domains, Computational Thinking and Computer Programming, and their intersection was used to guide this research.

In order to evaluate the impact of the *Augmented Resources* proposed and developed, experiments with real students in real classrooms to measure the results in learning activities were conducted.

The theoretical part of the Ph.D. work—covering the review of literature on AR and its application to learning activities, and the study of CT and LR—was reported along two chapters in Part I of this dissertation.

The exploration and experimental work—comprising the design, implementation, and testing of four innovative gadgets to train CT with AR elements—was presented and discussed in four chapters in Part II of the dissertation. Part II, which introduces some of the contributions of this doctoral project, also includes a fifth chapter that discusses another contribution: an AR-based tool that helps Computer Programming students understand programs dealing with complex data structures and operation over them.

Part III discusses two other contributions of this Ph.D. work. On one hand, a generalization of the approaches followed to build the LR discussed in Part II is presented. The guidelines proposed to build AR-based LR for training CT or to help on the teaching-learning process of CP are one of the major contributions of the thesis reported. On the other hand, another important outcome of this doctoral project was introduced: the design and realization of a high-level course on the use of AR technologies and its application to the development of resources to train CT.

This outcome, with two instances (academic years of 21/22 and 22/23), is manyfold. First of all, it corroborates the thesis here defended: it is feasible to incorporate AR technologies to build, without a huge effort, new motivation and engaging resources to train the skills contained in the CT principles. The activity, by itself, motivates the students of the Technical Institute to improve their programming knowledge and capabilities. Another positive result derives from the fact that this activity shows the pedagogical capabilities of the Thesis Author; Moreover, it was useful for the Institution and its Students as well as it enriched the Author's teaching curriculum.

When reviewing the tasks executed along the doctoral years, to highlight the main milestones that were decisive for the final results, it is important to mention, right at the beginning, the PhobiAR project. Participation, as co-supervisor, in the PhobiAR Master's project (more details below, in the next section), which entails an augmented reality artifact designed to aid in the exposure therapy of specific phobias, has evinced the potential that augmented reality technology can provide. The above mentioned step did not provide the experience necessary to accomplish the main purpose of this doctoral project,

Building a Game with Augmented Reality, but was actually crucial to master this technology.

The activities involved in the project's focus are intended to provide the improvement of skills related with CT, which is aligned with the activity of problem-solving; on account of that, they required a deeper investigation in the area. Virtual button techniques were exploited throughout the course of this project, thereby exploring a novel mode of interaction and an interface that facilitates a 360° evaluation of the 3D environment.

In the final stage, another important challenge was tackled, bearing the title *Visualization of Imperative Programs through Augmented Reality*. This undertaking serves to evince sustained motivation towards

the themes scrutinized and explored in the preceding stages, which are geared towards the creation of AR-based learning resources.

11.1 Collaborations

The first collaboration relevant, because it gave the context and motivation for the doctoral project presented and discussed in this document, was with the subgroup of the gEPL[1] involved in the project CnE[2], which is led by Pedro Rangel Henriques and is the theme of Cristiana Araújo's PhD. That Cooperation introduced the Author to the problematic around the teaching/learning of Computer Programming and to the topic of Computational Thinking as an important solution to overcome the generalized difficulties of novice programmers.

Complementing the doctoral work, the opportunity to co-supervise Master's Students of MEI[3] was crucial for the goals achieved.

Three dissertations were conducted to investigate different topics in the area of Augmented Reality. The titles are as follows:

- *An AR Artifact for Supporting the Treatment of Specific Phobias* by Raúl Vilas Boas, 2019/20—the outcome was a tool called PhobiAR (Boas, 2020);
- *Developing a Game with AR for Training CT* by Francisco Saraiva, 2021/22—the outcome was a game called Shrews (Saraiva, 2022);
- *Visualization of Imperative Programs using AR* by Luís Salazar Martins, 2022/23—the outcome is a tool called LCSMAR (Martins, 2023).

The first two were concluded successfully, and the third will be discussed before the end of the year. Moreover, each project gave rise to, at least, one paper published and presented in an international conference, as will be cited below.

Apart from the tool developed by Raúl Vilas Boas, which was relevant as a warm up project but did not contributed directly to this thesis outcome, the game Shrews created by Francisco Saraiva and the tool LCSMAR developed by Luís Martins were presented and discussed in Part II of this dissertation, as they had a direct impact in this thesis innovations.

[1] gEPL stands for *grupo de Especificação e Processamento de Linguagens* and denotes an academic group that belongs to Departamento de Informática da Universidade do Minho is devoted to teach and research all the topics regarding the formal definition and processing of languages (programming, annotation, and natural languages).

[2] CnE is the Portuguese acronym for *Computação na Escola*.

[3] Mestrado em Engenharia Informática, do Dep. de Informática da Universidade do Minho.

11.2 Publications

To disseminate the main results achieved along the preparation of the thesis, including those that sprang out from the collaborations referred above, various papers were written. This section lists the publications done:

- *An Ontology based approach to teach Computational Thinking* Araújo et al. (2019);
- *Artifact of Augmented Reality to Support the Treatment of Specific Phobias* Boas et al. (2020);
- *Training the Computational Thinking with Augmented Reality* V O Lima et al. (2020);
- *Learning Resources with Augmented Reality* Lima et al. (2020);
- *Understanding Effects of the Algorithm Visualized with AR Techniques* Lima et al. (2021);
- *SHREWS: A Game with AR for Training CT* Saraiva et al. (2021);
- *AR-based Resources to train CT Skills* Lima et al. (2023b);
- *Training CT with AR-based Resources- an Experiment in a classroom* Lima et al. (2022);
- *LCSMAR, an AR Based Tool to Inspect Imperative Programs* Martins et al. (2023);
- *AR-Based Learning Resource: A Different way to Learn Data-Structures* Lima et al. (2023a);

11.3 Future work

Many things are still needed to consolidate the thesis proposed here. Moreover, some other directions for future research arose from the work done. So, this section discusses future work.

On one hand, it is important to keep designing and conducting more experiments in real classrooms using the games—Make your Hero, Shrews, and the many others created by the different student teams—and the tool LCSMAR[4].

Of course, the experiments mentioned shall address the quality of the Apps usability, but they must essentially be designed to measure accurately how they improve the CT skills in the Users or how they impact the Users's understanding of imperative computer programs.

These experiments will be crucial to actually appraise the contributions so far proposed. However, they are also of uttermost relevance to improve the present games and tools taking into account all the feedback collected along the tests with students and teachers.

On the other hand, it is important to keep investigating other technological approaches to make tools like LCSMAR more appealing and helpful taking the most from the enrichment of the textual programming

[4] LVL and LCSMAR have being less tested and on account of that their experimentation and assessment deserves at moment special attention.

activity with virtual 3D images. The most difficult challenge in this proposal has been overcome, however, the advances registered so far promise that there are still pathes for further improvements

Concerning the teaching and collaborative activities, there are also open possibilities. There have been positive outcomes stemming from the course *Introduction to Virtual and Augmented Systems* dictated in the Technology and Systems curriculum at Federal Institute of Brasilia (Brazil), as mentioned in the last chapter, which generated innovations in the AR field every semester (until now, two instances have occurred). The referred course applies the principles of this thesis disseminating the cutting-edge technologies for the creation of AR-based Learning Resources. The opportunity to keep offering this course is, clearly, a good chance to go further exploiting the potential for creating AR-based learning resources suitable for various age groups and using different approaches. Additionally, it is important to look for bilateral cooperation programs to instigate the partnership of Brazilian Federal Institutes and different European countries. For that purpose, Student or Teacher exchange programs shall be identified to contribute to the dissemination of the outcomes so far attained and keep on exploring those ideas.

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Appendix A

MAREEA Questionnaire

In this appendix, the complete form with the questions to assess AR software following MAREEA (Evaluation Model of Mobile Augmented Reality Educational Approaches) proposal is presented.

MAREEA - Evaluation model of Mobile Augmented Reality Educational Approaches

App Name:	
Institution Name:	
Subject / Series / Class:	
Age range:	☐ Under 10 years ☐ 10 to 14 years ☐ 15 to 19 years ☐ 20 to 24 years ☐ 25 to 29 years ☐ 30 to 34 years ☐ 35 to 39 years ☐ 40 to 44 years ☐ 45 to 49 years ☐ Over 50 years
Genre:	☐ Male ☐ Female

Affirmations	**Check the option that best represents your rating**				
	Strongly disagree	**Disagree**	**Neither disagree nor agree**	**Agree**	**Totally agree**
I needed to learn a few things before I could use this augmented reality app.	☐	☐	☐	☐	☐
Learning to use this augmented reality app was easy.	☐	☐	☐	☐	☐
This augmented reality app is easy to use.	☐	☐	☐	☐	☐
The way to use this augmented reality app is easy to understand.	☐	☐	☐	☐	☐
The design (color, font style, and size) used in this augmented reality app is clear and readable.	☐	☐	☐	☐	☐
This augmented reality app makes it difficult for me to make mistakes.	☐	☐	☐	☐	☐
In case of a mistake, it is easy to recover from it quickly.	☐	☐	☐	☐	☐
The interface of this augmented reality app is attractive.	☐	☐	☐	☐	☐
I like the graphics information presented in this augmented reality app.	☐	☐	☐	☐	☐
The educational content on this augmented reality app is worthwhile.	☐	☐	☐	☐	☐
My experience with this augmented reality app was rewarding.	☐	☐	☐	☐	☐
I felt involved in the tasks of this augmented reality app.	☐	☐	☐	☐	☐
The learning experience with this augmented reality app was fun.	☐	☐	☐	☐	☐
The educational content of this augmented reality app sparked my curiosity.	☐	☐	☐	☐	☐
I got interested in this augmented reality app.	☐	☐	☐	☐	☐
I was so involved in the task with this augmented reality app that I lost track of time.	☐	☐	☐	☐	☐
I ignored things around me when I was using this augmented reality app.	☐	☐	☐	☐	☐
The way the information is arranged in this augmented reality app helped keep my attention.	☐	☐	☐	☐	☐
It is clear to me how the educational content of this augmented reality app is related to the things I know.	☐	☐	☐	☐	☐
Successfully completing the lesson with this augmented reality app was important to me.	☐	☐	☐	☐	☐
I am confident that I learned what I was supposed to after using this augmented reality app.	☐	☐	☐	☐	☐
I am confident that I understood the most complex educational content using this augmented reality app.	☐	☐	☐	☐	☐
Completing the activities in this augmented reality app gave me a satisfying feeling of accomplishment.	☐	☐	☐	☐	☐
I enjoyed the educational content of this augmented reality app so much that I would like to know more about this topic.	☐	☐	☐	☐	☐
I really enjoyed studying with this augmented reality app.	☐	☐	☐	☐	☐
This augmented reality app allowed me to better understand the educational content.	☐	☐	☐	☐	☐
I will be able to apply what I learned with this augmented reality app in other activities.	☐	☐	☐	☐	☐

The simulations of this augmented reality app are useful to my learning.	☐	☐	☐	☐	☐
This augmented reality app challenged me to learn new things.	☐	☐	☐	☐	☐
In this augmented reality app I choose assignments that I can learn.	☐	☐	☐	☐	☐
This augmented reality app provided opportunities to experience information through visual feedback.	☐	☐	☐	☐	☐
This augmented reality app provided opportunities to experience information through audio feedback.	☐	☐	☐	☐	☐
This augmented reality app allows me to interact with simulations that it I would hardly perform in the real world.	☐	☐	☐	☐	☐
The simulations in this augmented reality app were appropriate for a learning experience.	☐	☐	☐	☐	☐
The simulations in this augmented reality app are useful to practice the real-life cases before performing them on the real lab.	☐	☐	☐	☐	☐
This augmented reality app presented real-world problems through simulations.	☐	☐	☐	☐	☐
I like to use this augmented reality app in my hands-on training.	☐	☐	☐	☐	☐

Report aspects you liked about the app, features that could be improved in the app, or any app or mobile device-related difficulties.

_____

_____

_____

_____

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Appendix B

Results of Make Your Hero Experiment

This appendix shows, in graphical format, the answers to MAREEA Questionnaire collected from students during the experiment conducted to appraise the Learning Resource Make Your Hero, as described in section 9.1.

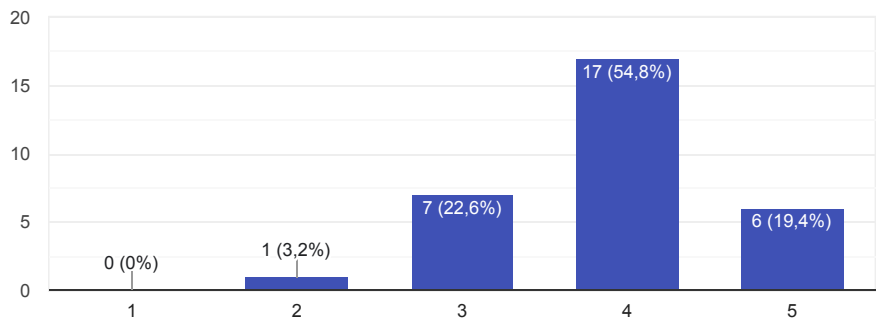
MAREEA(Evaluation Model of Mobile Augmented Reality Educational Approaches) - Maker Hero AR

31 respostas

1 - I needed to learn a few things before I could use this augmented reality app.

Copiar

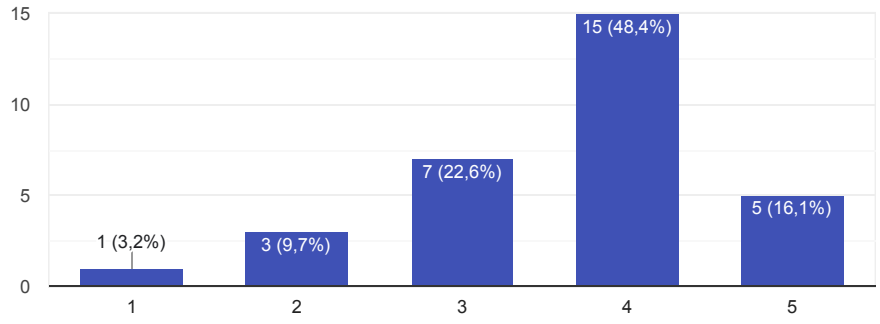
31 respostas



2 - Learning to use this augmented reality app was easy.

Copiar

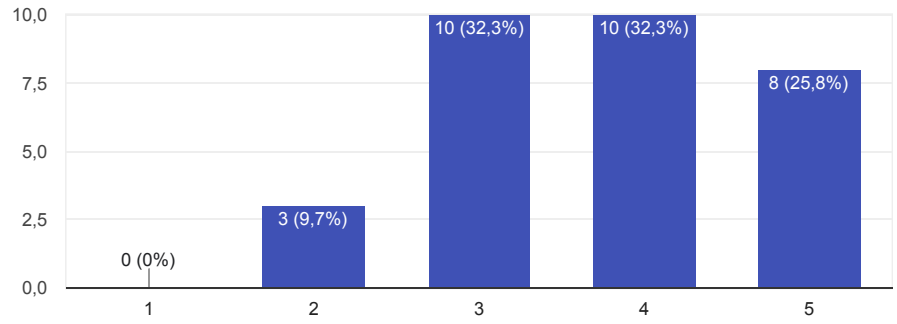
31 respostas



3 - This augmented reality app is easy to use.

Copiar

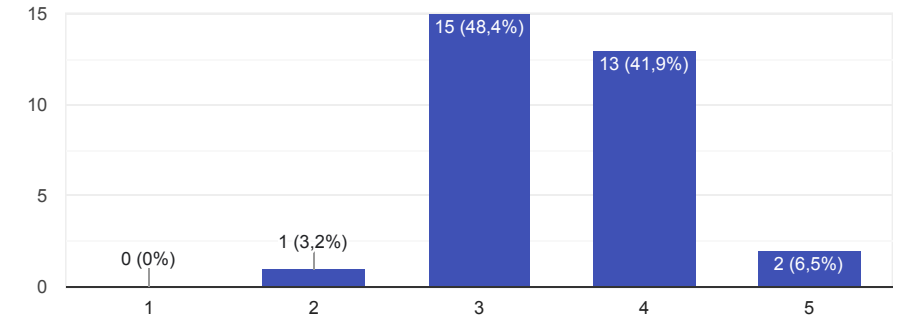
31 respostas



4 - The way to use this augmented reality app is easy to understand.

Copiar

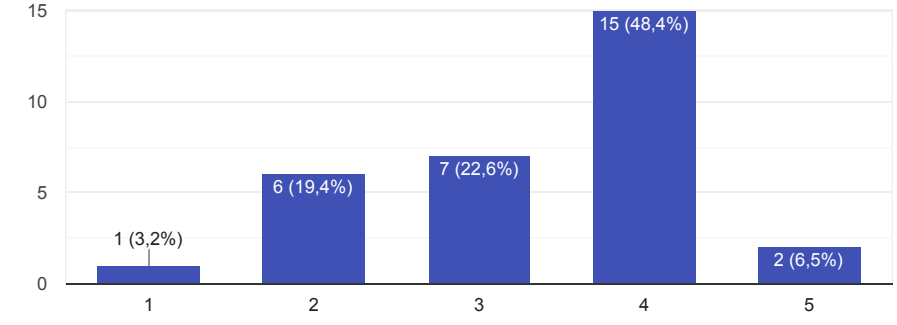
31 respostas



5 - The design (color, font style, and size) used in this augmented reality app is clear and readable.

Copiar

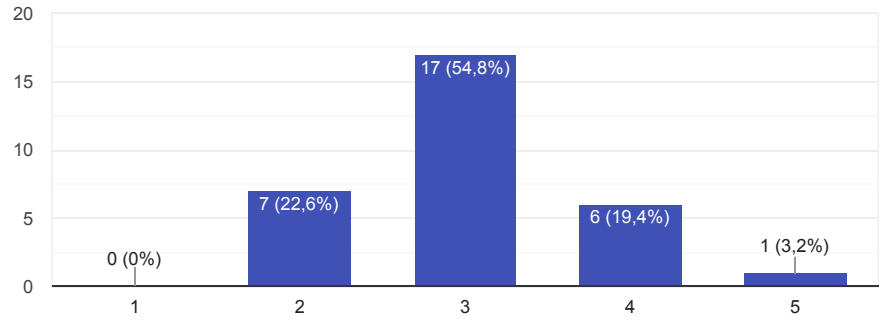
31 respostas



6 - This augmented reality app makes it difficult for me to make mistakes.

Copiar

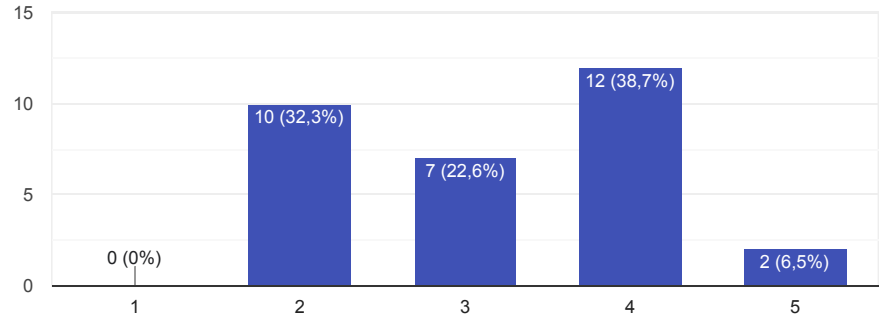
31 respostas



7 - In case of a mistake, it is easy to recover from it quickly.

Copiar

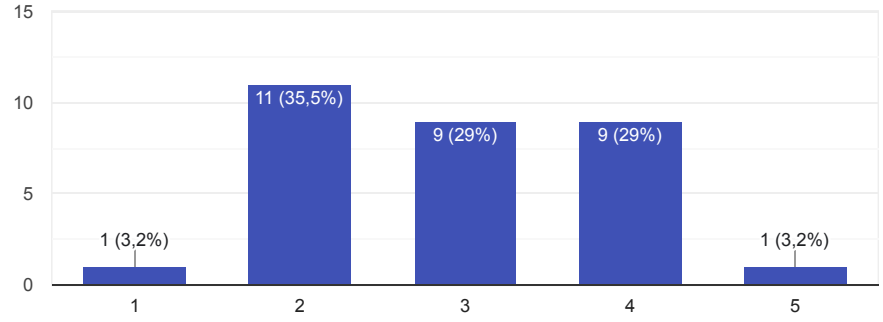
31 respostas



8 - The interface of this augmented reality app is attractive.

Copiar

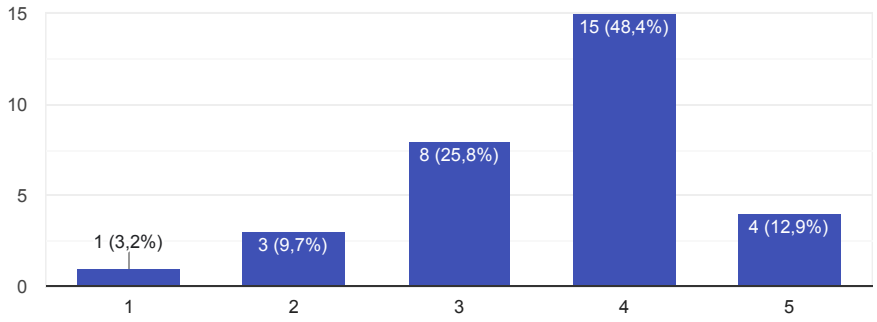
31 respostas



9 - I like the graphics information presented in this augmented reality app.

Copiar

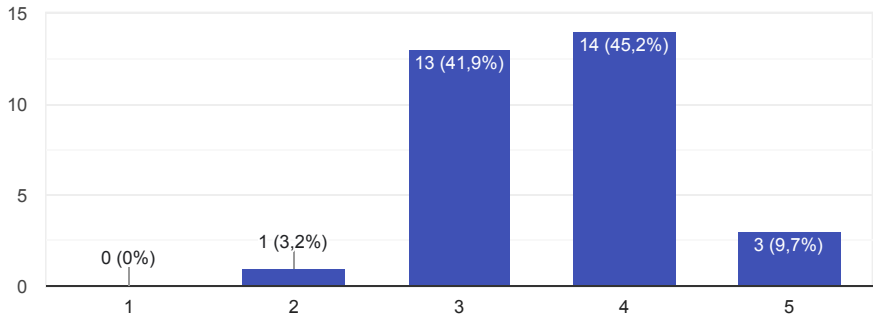
31 respostas



10 - The educational content on this augmented reality app is worthwhile.

Copiar

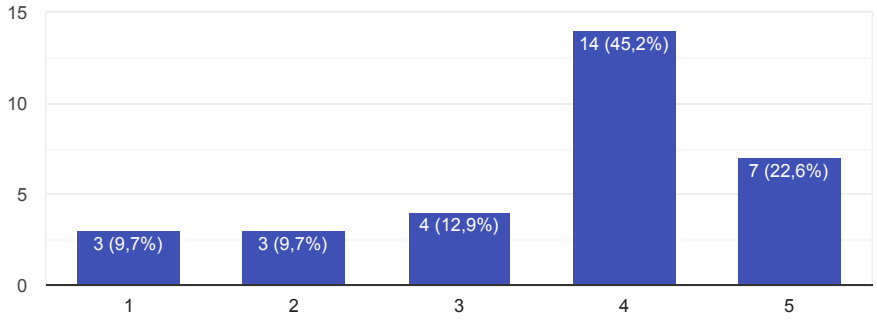
31 respostas



11 - My experience with this augmented reality app was rewarding.

Copiar

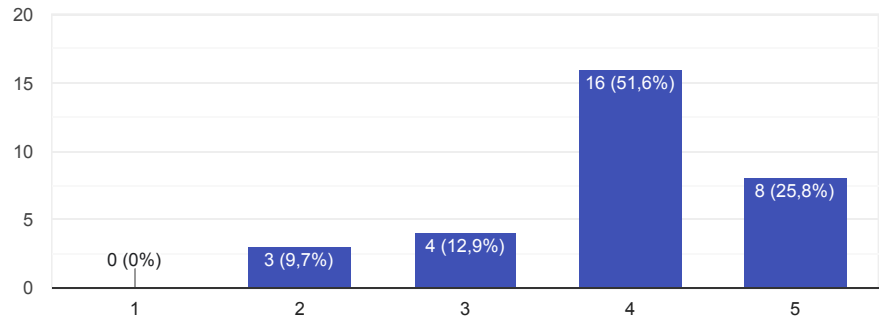
31 respostas



12 - I felt involved in the tasks of this augmented reality app.

Copiar

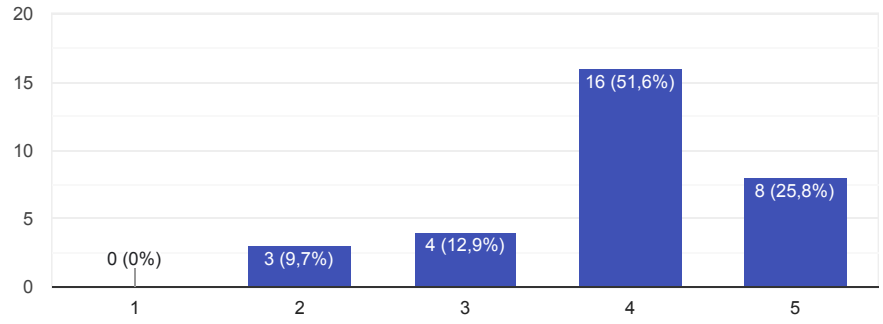
31 respostas



13 - The learning experience with this augmented reality app was fun.

Copiar

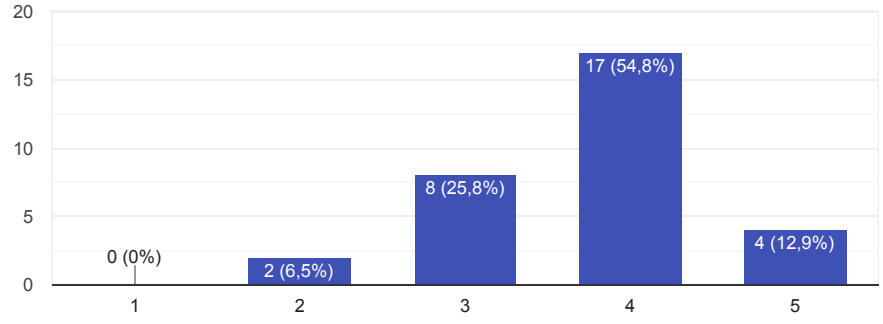
31 respostas



14 - The educational content of this augmented reality app sparked my curiosity.

Copiar

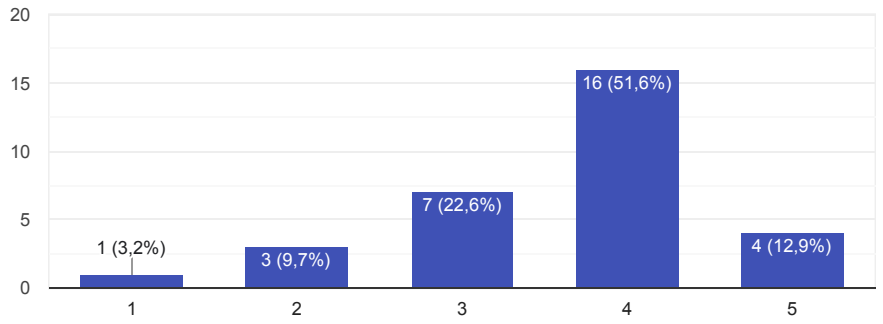
31 respostas



15 - I got interested in this augmented reality app.

Copiar

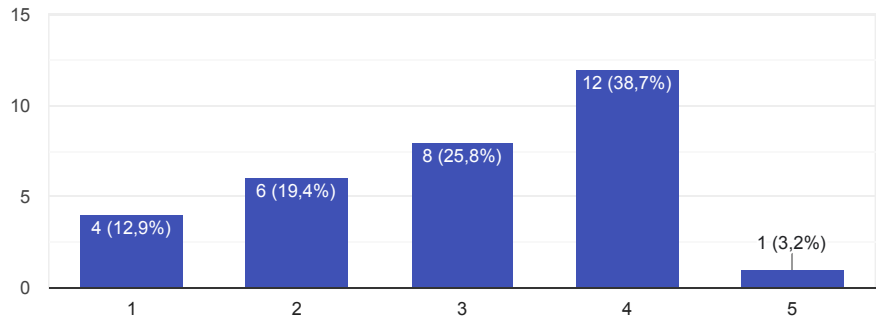
31 respostas



16 - I was so involved in the task with this augmented reality app that I lost track of time.

Copiar

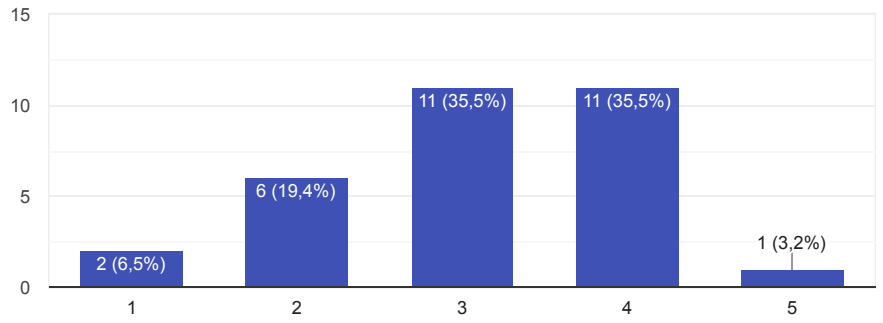
31 respostas



17 - I ignored things around me when I was using this augmented reality app.

Copiar

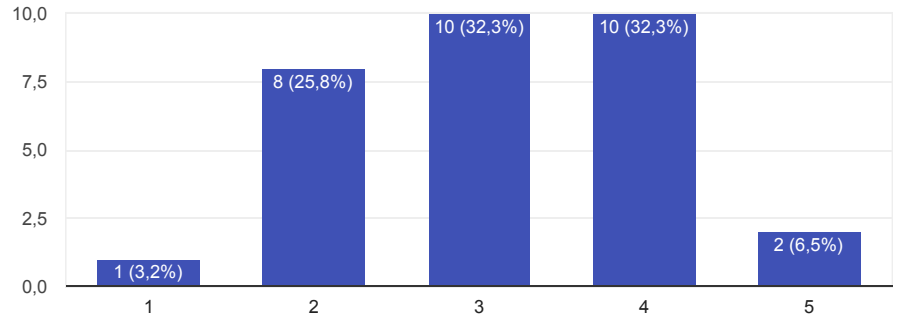
31 respostas



18 - The way the information is arranged in this augmented reality app helped keep my attention.

Copiar

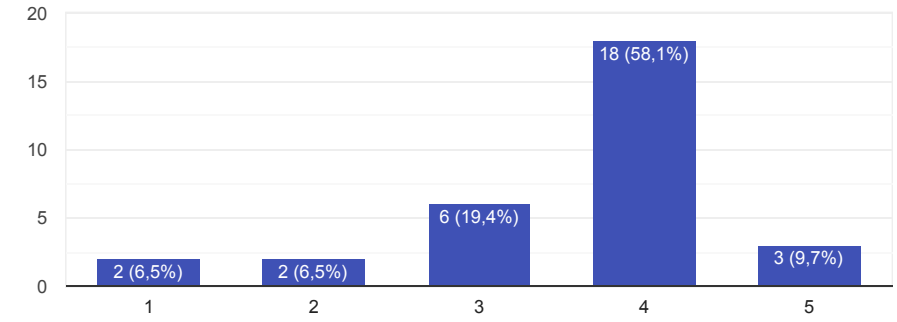
31 respostas



19 - It is clear to me how the educational content of this augmented reality app is related to the things I know.

Copiar

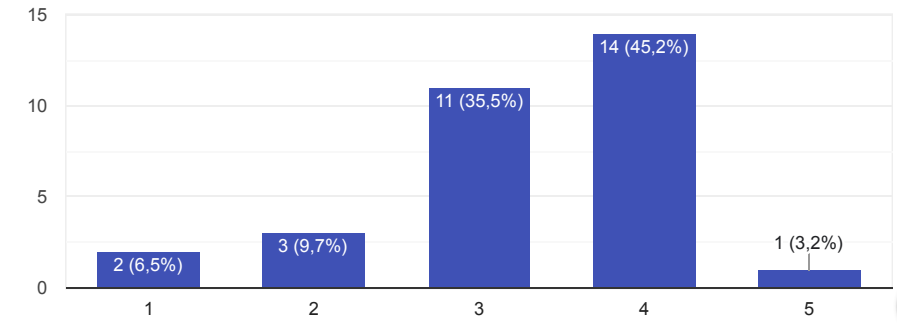
31 respostas



20 - Successfully completing the lesson with this augmented reality app was important to me.

Copiar

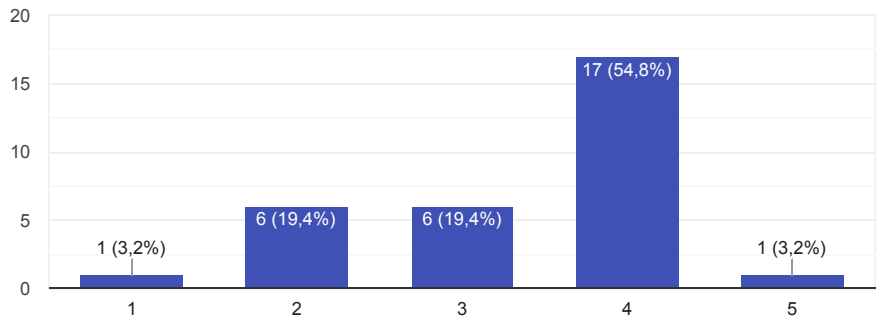
31 respostas



21 - I am confident that I learned what I was supposed to after using this augmented reality app.

Copiar

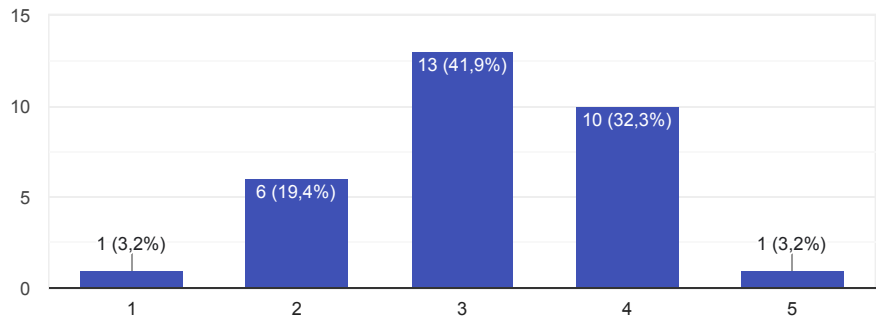
31 respostas



22 - I am confident that I learned what I was supposed to after using this augmented reality app.

Copiar

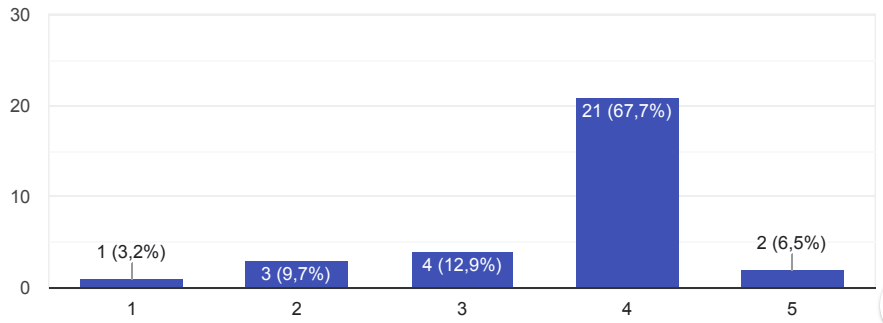
31 respostas



23 - Completing the activities in this augmented reality app gave me a satisfying feeling of accomplishment.

Copiar

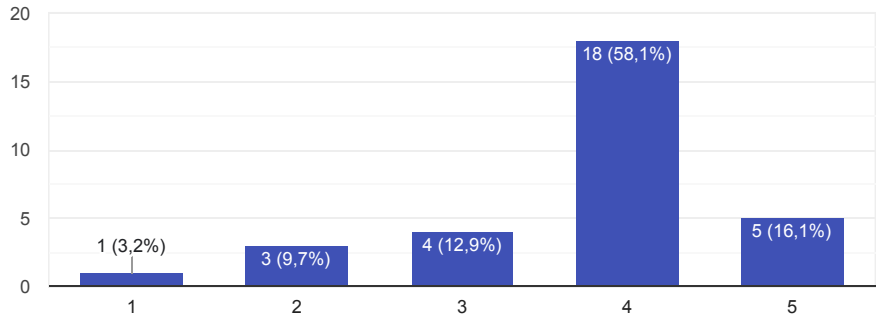
31 respostas



24 - I enjoyed the educational content of this augmented reality app so much that I would like to know more about this topic.

Copiar

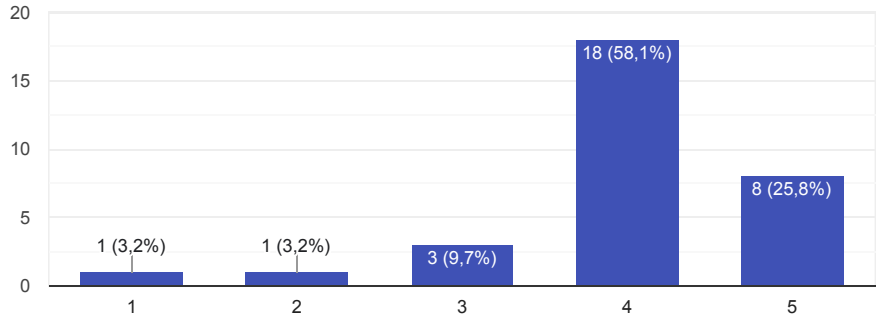
31 respostas



25 - I really enjoyed studying with this augmented reality app.

Copiar

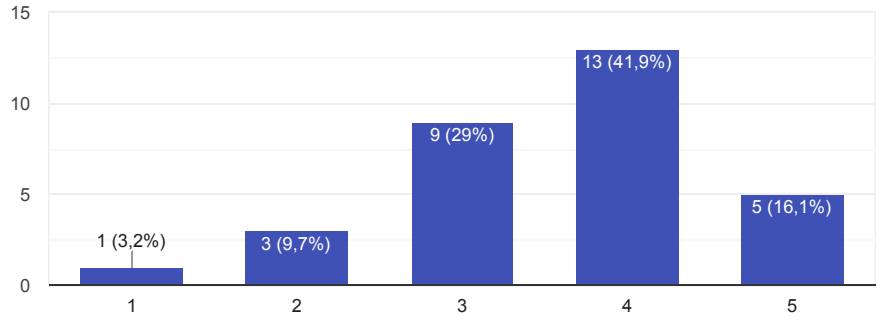
31 respostas



26 -This augmented reality app allowed me to better understand the educational content.

Copiar

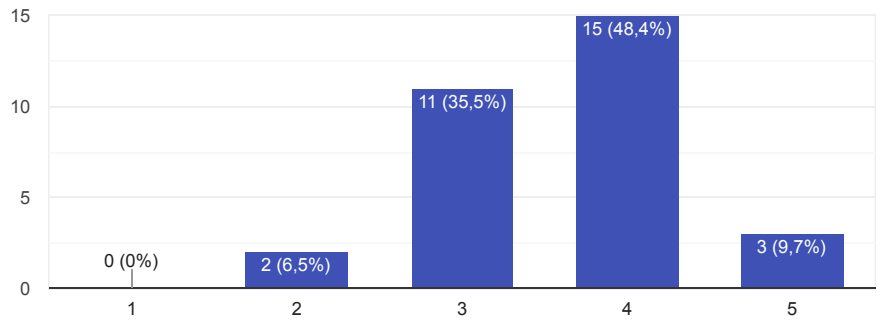
31 respostas



27 - I will be able to apply what I learned with this augmented reality app in other activities.

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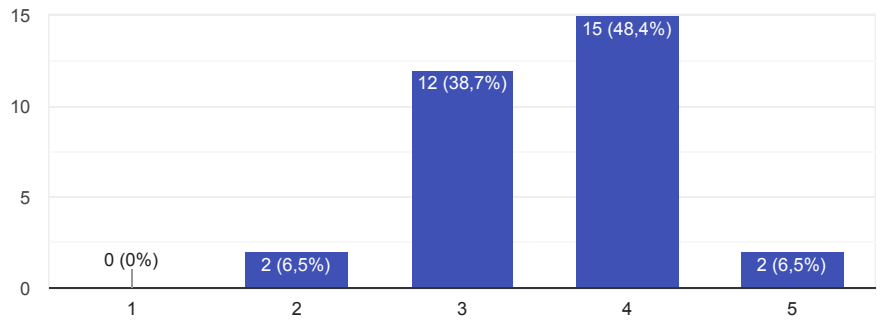
31 respostas



28 - The simulations of this augmented reality app are useful to my learning.

Copiar

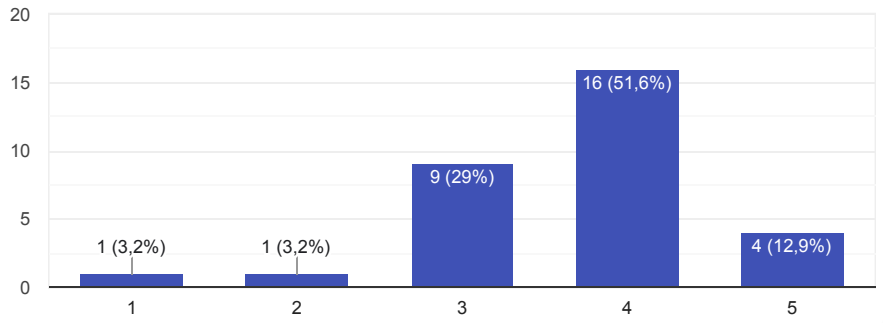
31 respostas



29 - This augmented reality app challenged me to learn new things.

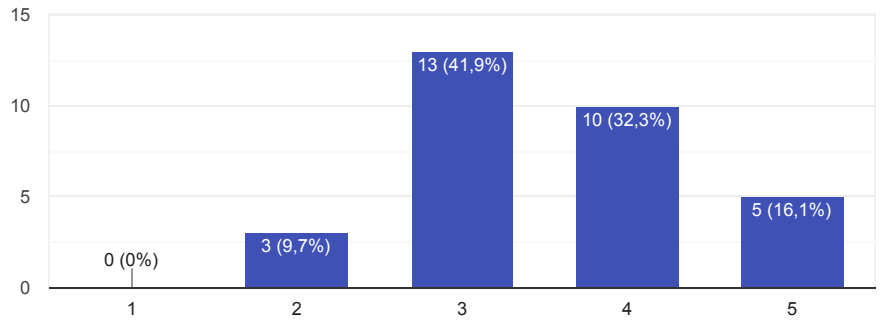
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31 respostas



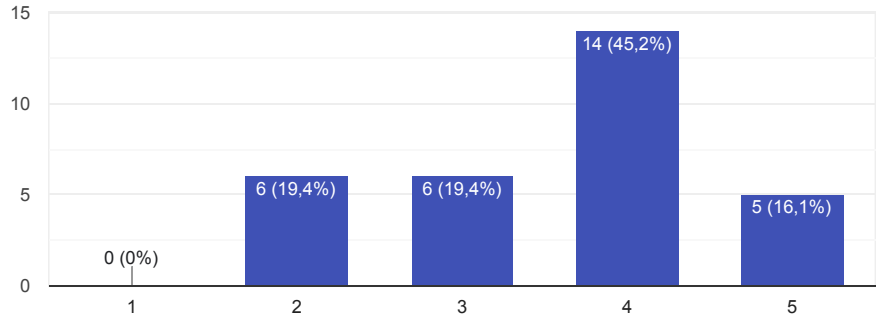
30 - In this augmented reality app I choose assignments that I can learn. Copiar

31 respostas



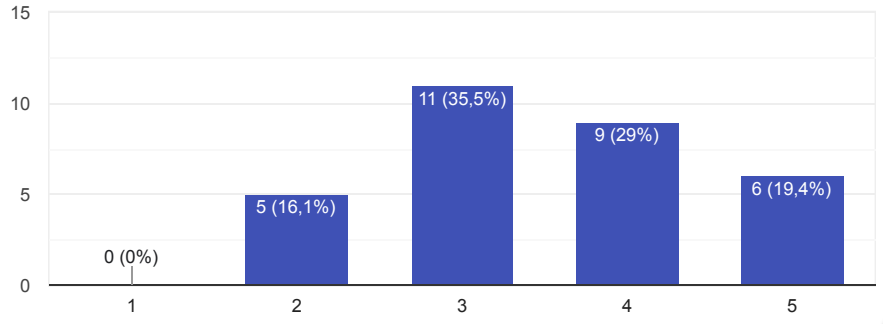
31 - This augmented reality app provided opportunities to experience information through visual feedback. Copiar

31 respostas



32 - This augmented reality app provided opportunities to experience information through audio feedback. Copiar

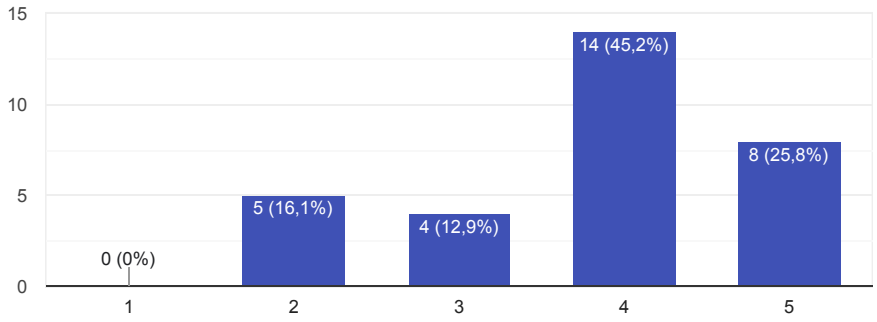
31 respostas



33 - This augmented reality app allows me to interact with simulations that it I would hardly perform in the real world.

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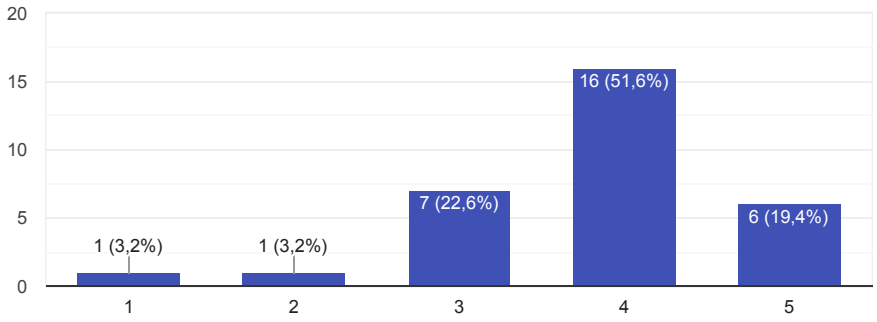
31 respostas



34 - The simulations in this augmented reality app were appropriate for a learning experience.

Copiar

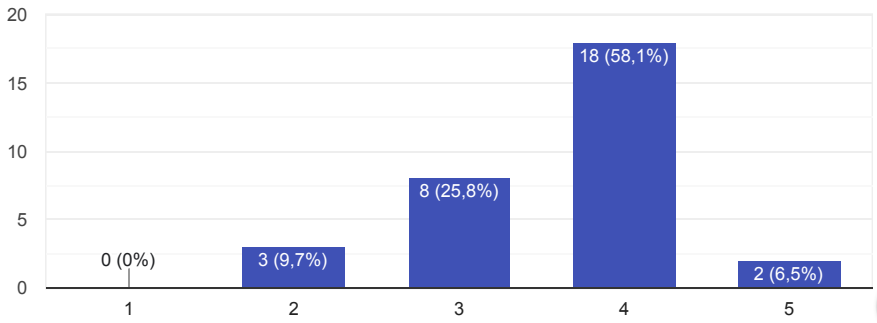
31 respostas



35 - The simulations in this augmented reality app are useful to practice the real-life cases before performing them on the real lab.

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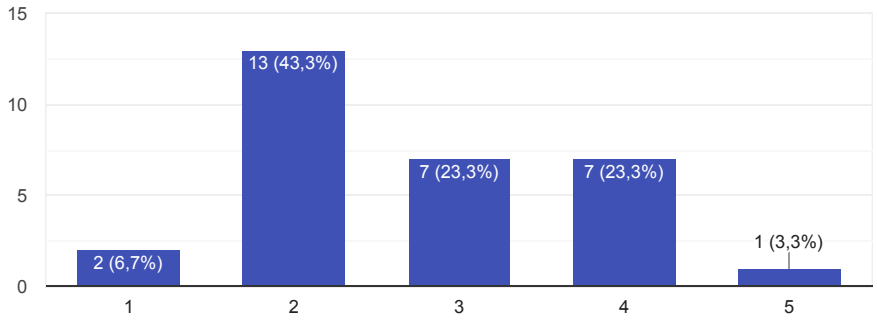
31 respostas



36 -This augmented reality app presented real-world problems through simulations.

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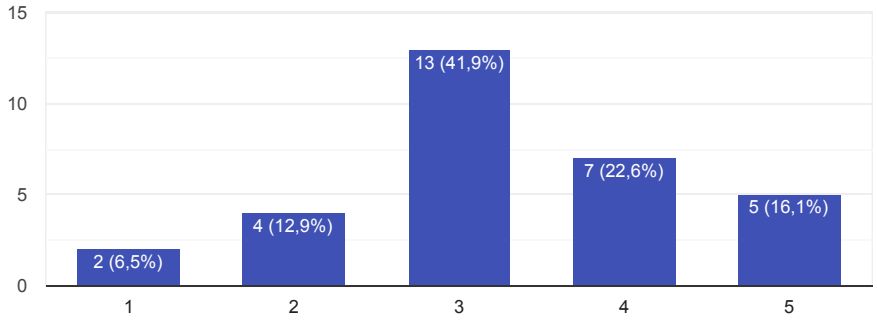
30 respostas



37 - I like to use this augmented reality app in my hands -on training.

Copiar

31 respostas



O que achou

26 respostas

sem comentários

resposta dupla

Tudo, amei

resposta feminina

Deveria melhorar na questão das cartas, acho um sistema falho , pois as cartas não deram muito bem no meu celular. A camera não foca na maioria dos casos.

Gostei de tudo no app

Dificuldade para estabilizar os personagens, as vees buga o app, o menu ta dando erro na criação de personagem as opções ficam uma em cima da outra

Gostei muito da ideia do aplicativo, porem a interface não é muito bonita e aconteceram varios erros durante o uso.

ter melhor informação na interface

e uma otima maneira para você experimentar a realidade aumentada

achei o app legal, mas foi dificil usar em celulares antigos

sem comentário

aplicativo mal otimizado , travadas

acho que a cor da fonte (amarela) alem de ser cansativa, nao ficou bom visualmente.
amei o jogo, gostaria de interagir com os herois dos meus amigos.

Disponibilidade para o sistema IOS, correção do erro que o aplicativo sai do funcionamento e sem mais simplificando a interface.

modo arena, online e Player vs player

Depois que você salva o personagem, vai em personagens salvos e se você quiser reabrir o personagem, você não consegue

tivemos probrmas para entrar no jogo, talvez uma função para focar a camera melhoraria a experiênicia.
A ideia foi criativa e divertida, e nos agradou.

O design tambem é bom, mas pode melhorar
O jogo não é ruim.

Gostei porque tem herois e monstros diferentes. As dificuldades foi as de relacionar as fichas para jogar

Poderia ter um acesso mais prático e ter uma forma melhor para acessar os qr codes.

Este conteúdo não foi criado nem aprovado pelo Google. Denunciar abuso - Termos de Serviço - Política de Privacidade

Google Formulários

Appendix C

Results of Shrews Experiment

This appendix shows, in graphical format, the answers to MAREEA Questionnaire collected from students during the experiment conducted to appraise the Learning Resource Shrews, as described in section 9.2.

MAREEA(Evaluation Model of Mobile Augmented Reality Educational Approaches)- Shrews

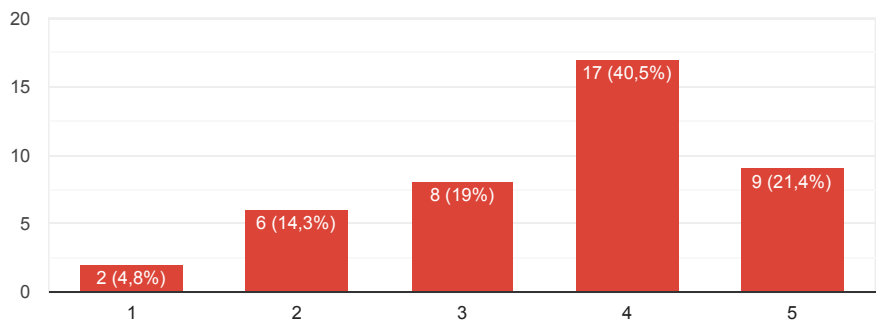
42 respostas

Publicar análise

1 - I needed to learn a few things before I could use this augmented reality app.

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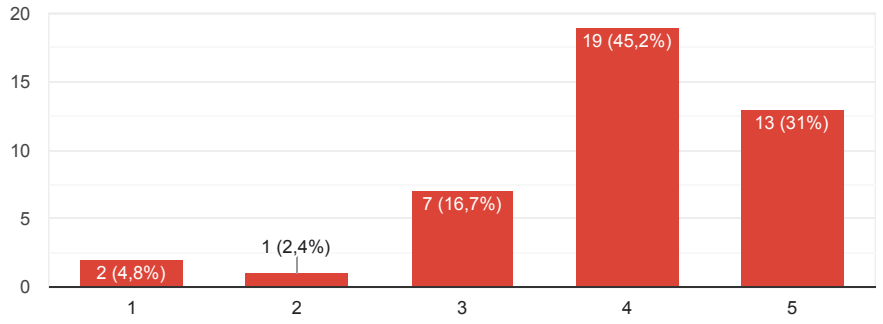
42 respostas



2 -Learning to use this augmented reality app was easy.

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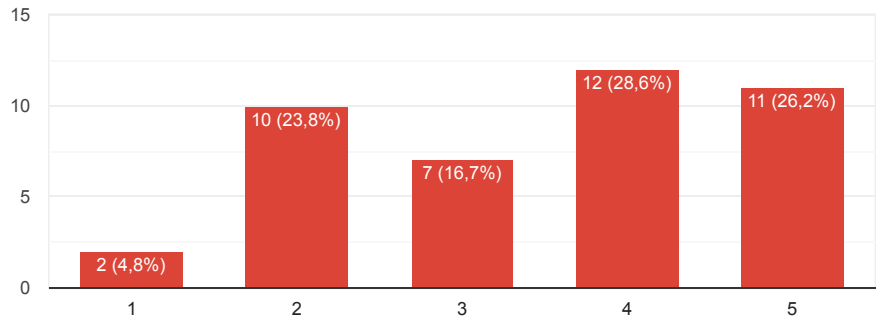
42 respostas



3 - This augmented reality app is easy to use.

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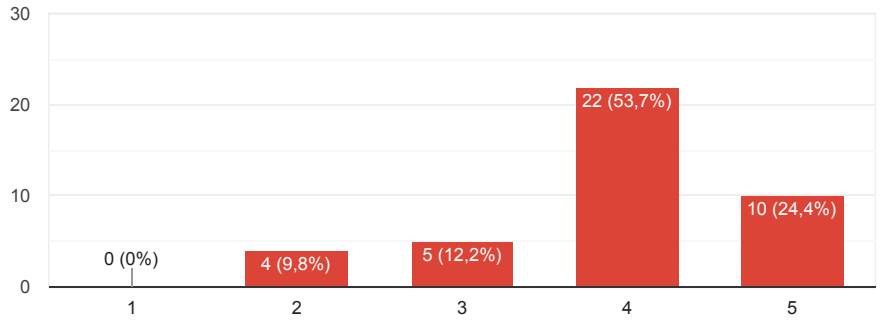
42 respostas



4 - The way to use this augmented reality app is easy to understand.

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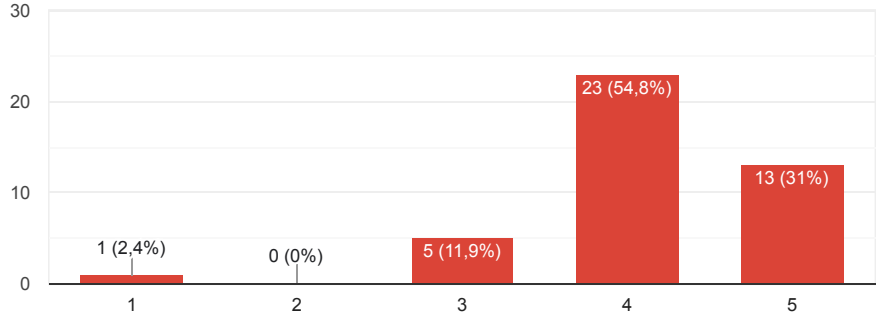
41 respostas



5 - The design (color, font style, and size) used in this augmented reality app is clear and readable.

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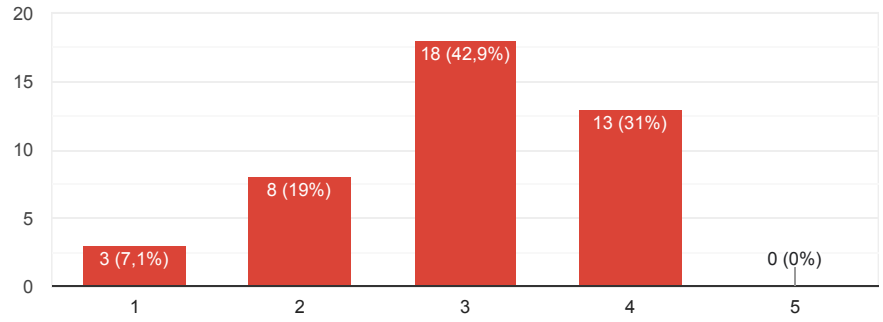
42 respostas



6 - This augmented reality app makes it difficult for me to make mistakes.

Copiar

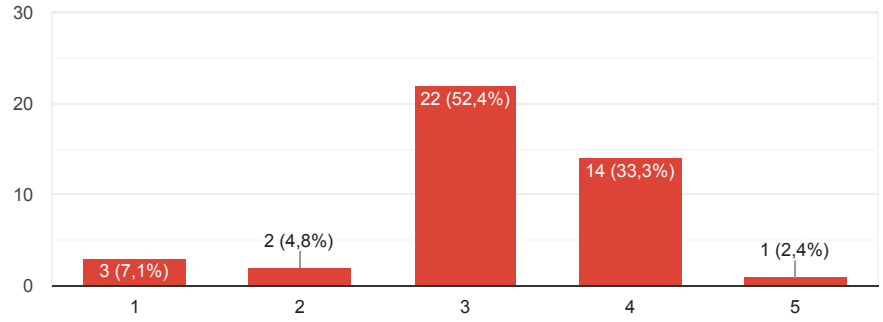
42 respostas



7 - In case of a mistake, it is easy to recover from it quickly.

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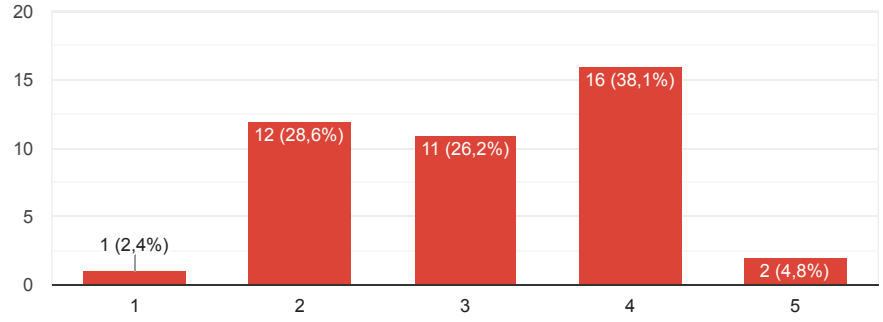
42 respostas



8 - The interface of this augmented reality app is attractive.

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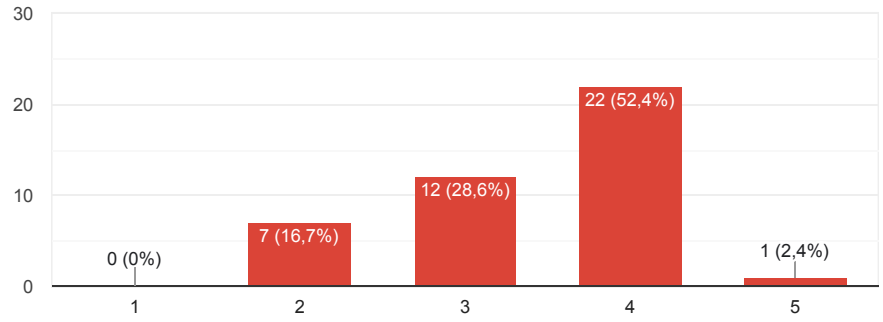
42 respostas



9 - I like the graphics information presented in this augmented reality app.

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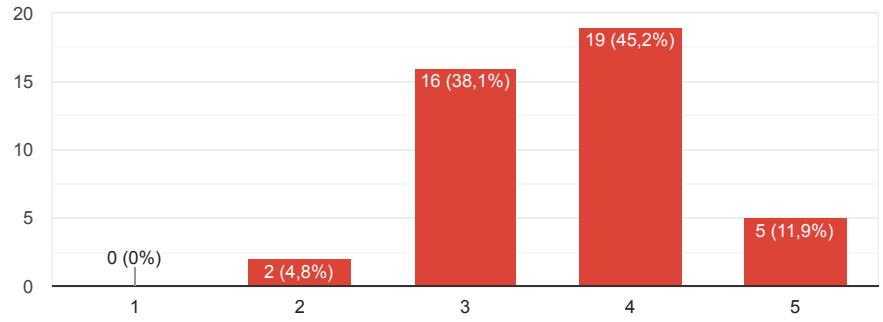
42 respostas



10 - The educational content on this augmented reality app is worthwhile.

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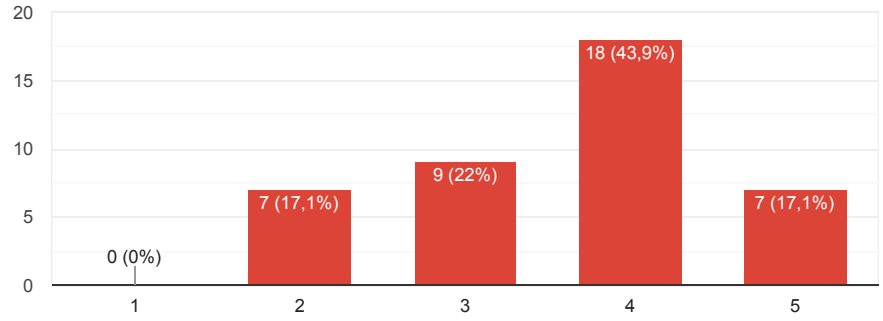
42 respostas



11 - My experience with this augmented reality app was rewarding.

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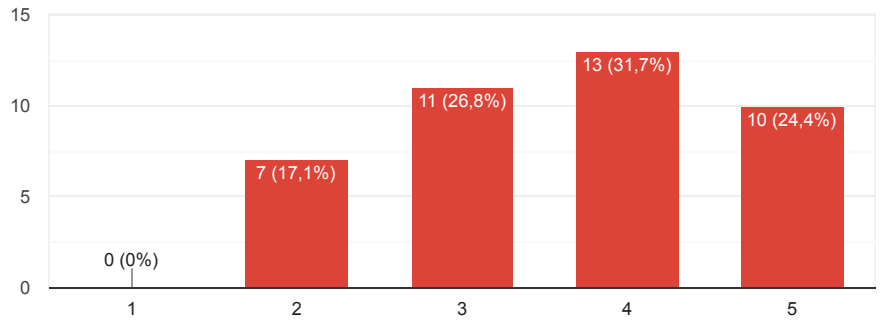
41 respostas



12 - I felt involved in the tasks of this augmented reality app.

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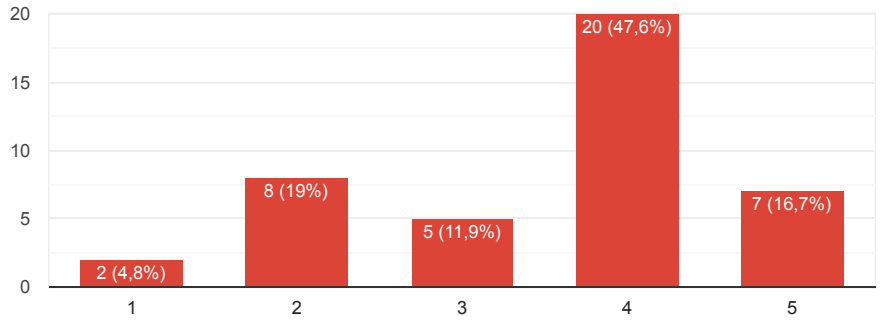
41 respostas



13 - My experience with this augmented reality app was rewarding.

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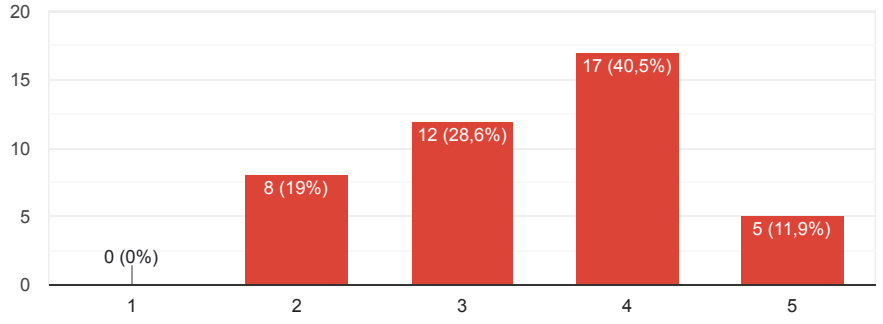
42 respostas



14 - The educational content of this augmented reality app sparked my curiosity.

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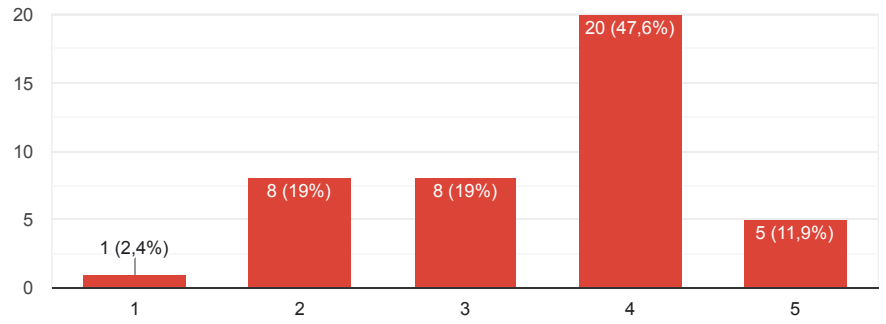
42 respostas



15 - I got interested in this augmented reality app.

Copiar

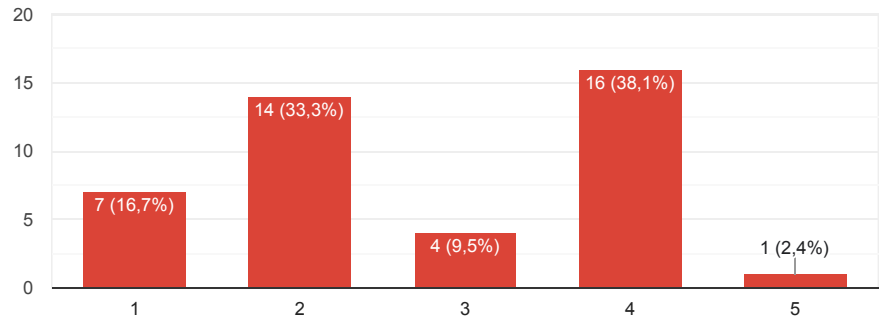
42 respostas



16 - I was so involved in the task with this augmented reality app that I lost track of time.

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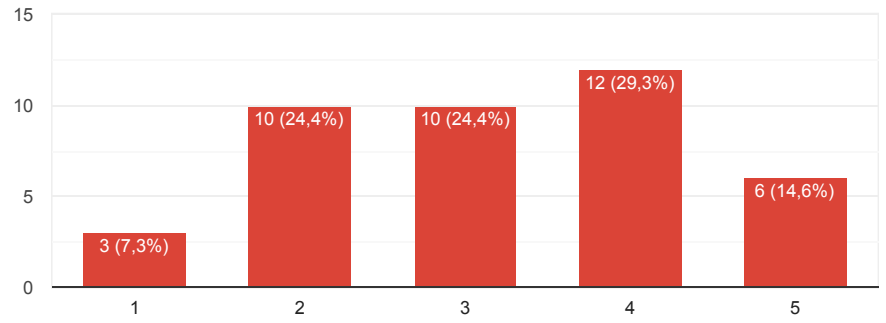
42 respostas



17 - I ignored things around me when I was using this augmented reality app.

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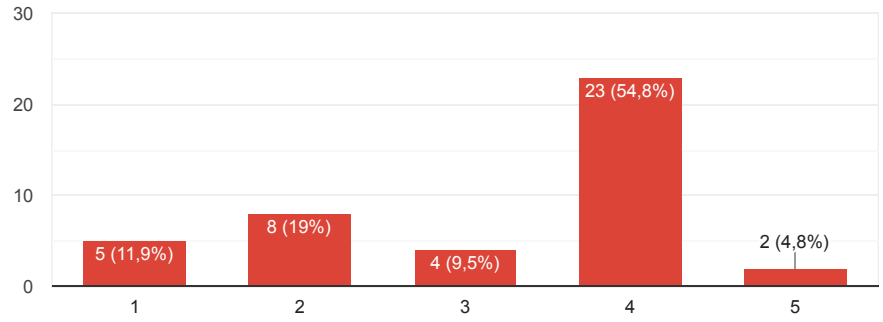
41 respostas



18 - The way the information is arranged in this augmented reality app helped keep my attention.

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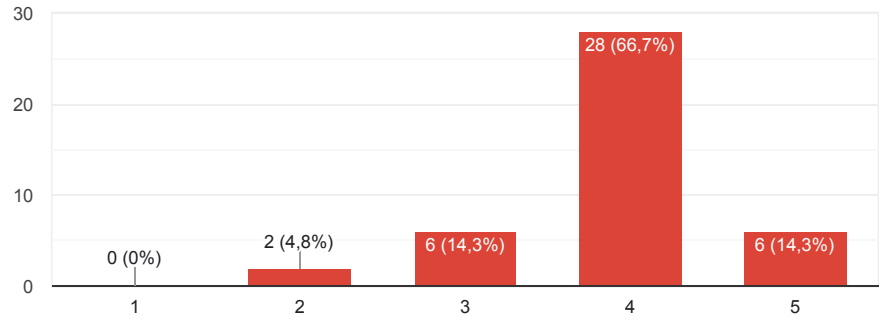
42 respostas



19 - It is clear to me how the educational content of this augmented reality app is related to the things I know.

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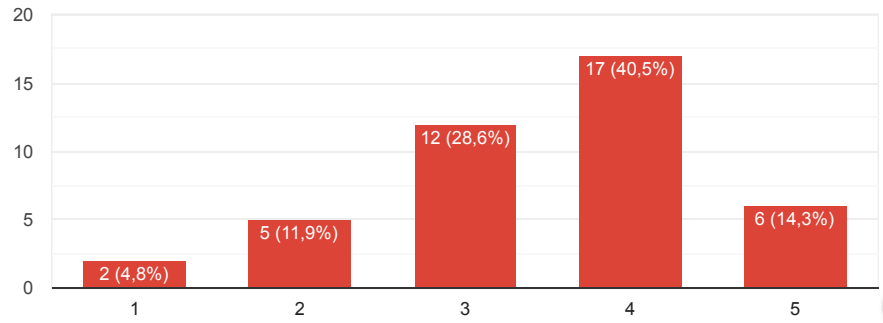
42 respostas



20 - Successfully completing the lesson with this augmented reality app was important to me.

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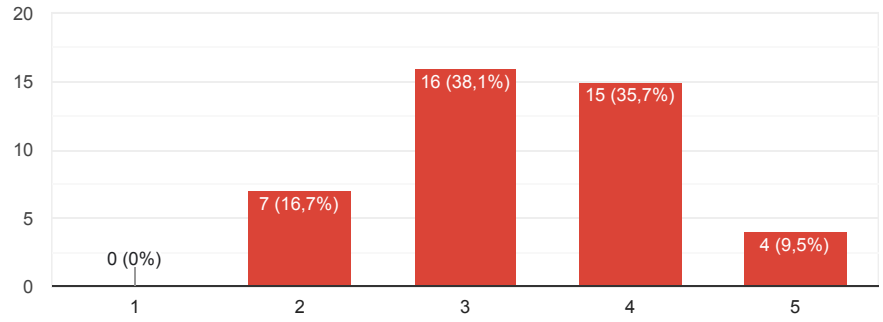
42 respostas



21 - I am confident that I learned what I was supposed to after using this augmented reality app.

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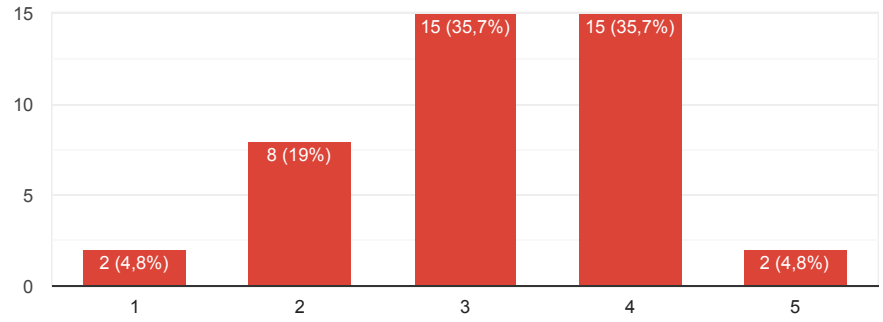
42 respostas



22 - I am confident that I understood the most complex educational content using this augmented reality app.

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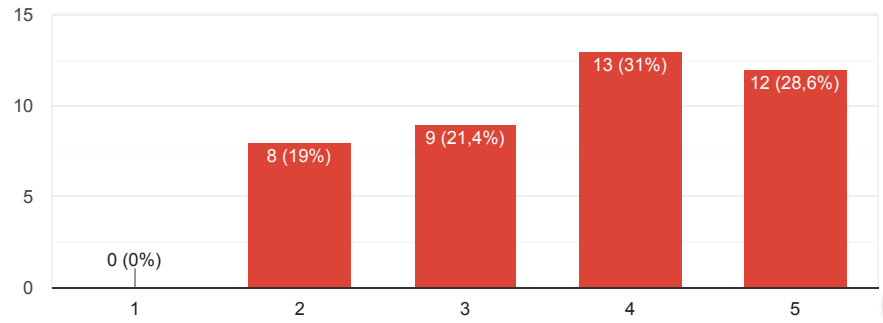
42 respostas



23 - Completing the activities in this augmented reality app gave me a satisfying feeling of accomplishment.

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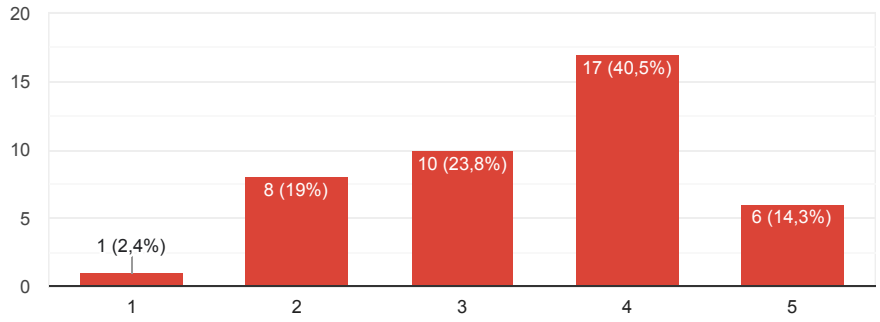
42 respostas



24 - I enjoyed the educational content of this augmented reality app so much that I would like to know more about this topic.

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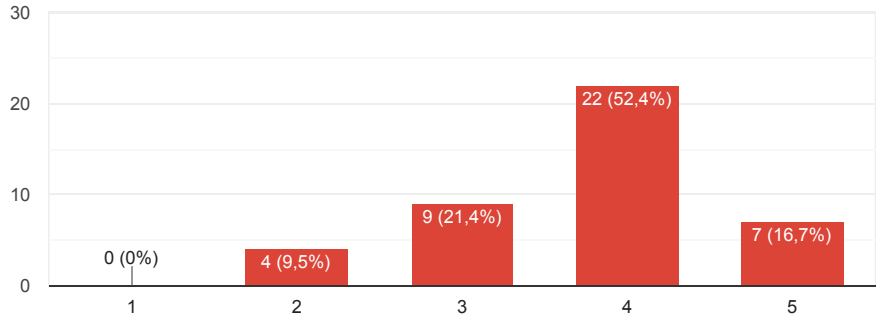
42 respostas



25 - I really enjoyed studying with this augmented reality app.

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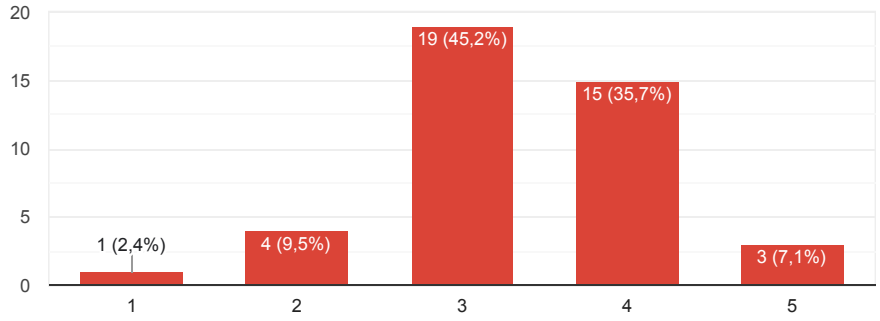
42 respostas



26 - This augmented reality app allowed me to better understand the educational content.

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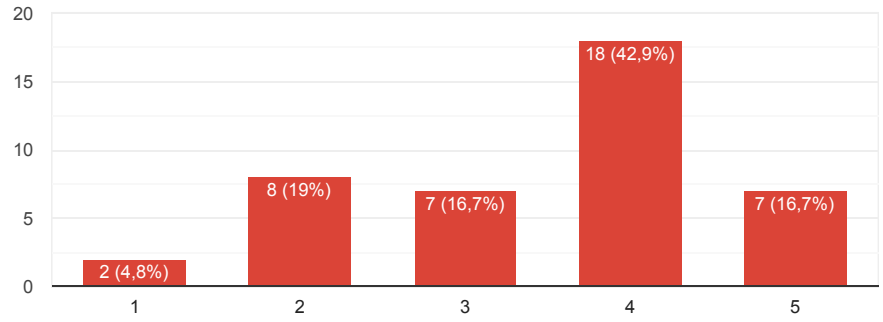
42 respostas



27 - I will be able to apply what I learned with this augmented reality app in other activities.

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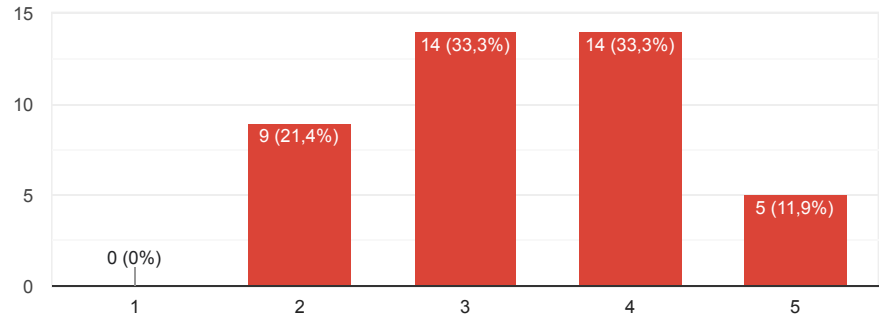
42 respostas



28 - The simulations of this augmented reality app are useful to my learning.

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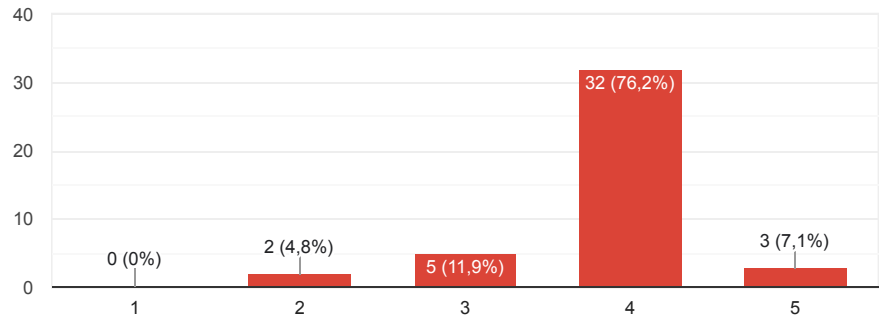
42 respostas



29 - This augmented reality app challenged me to learn new things.

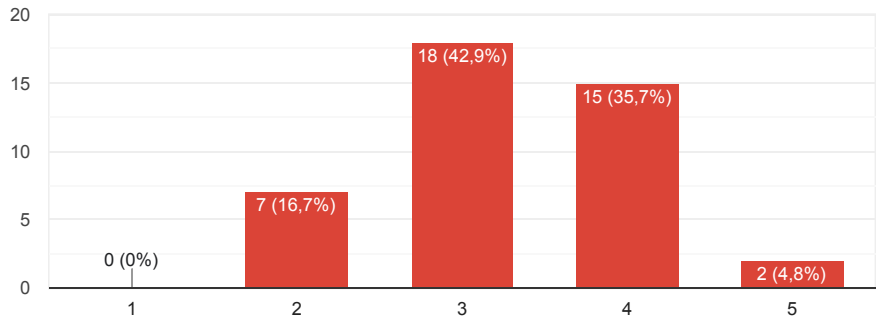
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42 respostas



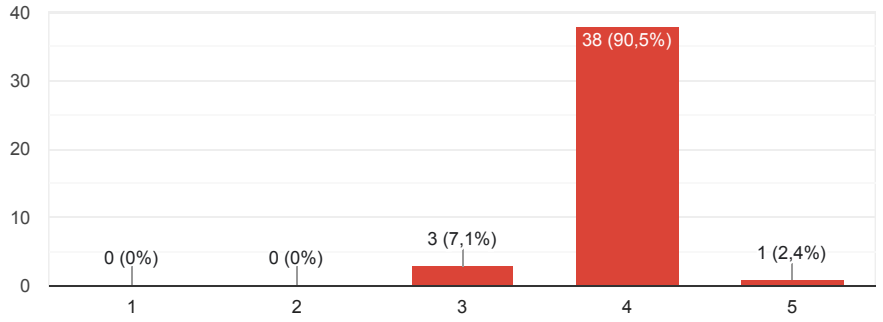
30 - In this augmented reality app I choose assignments that I can learn. Copiar

42 respostas



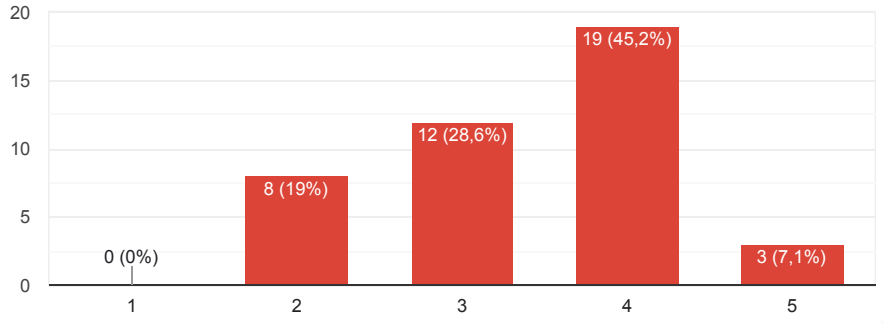
31 - This augmented reality app provided opportunities to experience information through visual feedback. Copiar

42 respostas



32 - This augmented reality app provided opportunities to experience information through audio feedback. Copiar

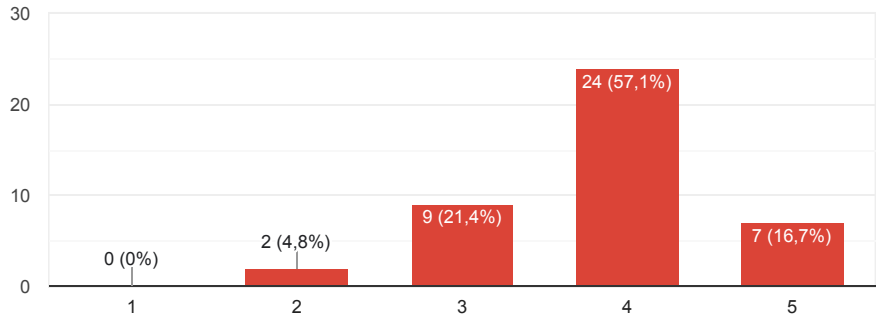
42 respostas



33 - This augmented reality app allows me to interact with simulations that it I would hardly perform in the real world.

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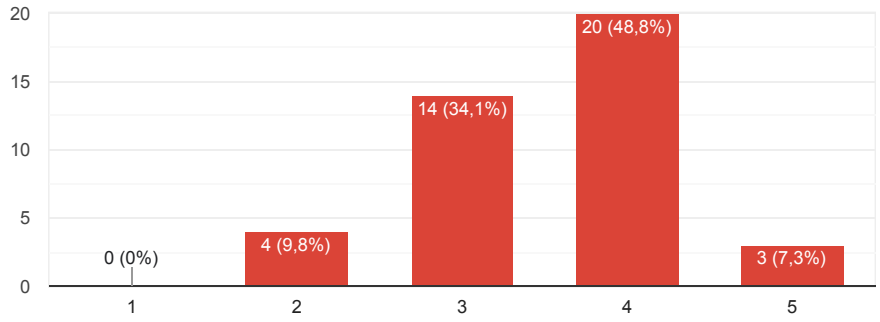
42 respostas



34 - The simulations in this augmented reality app were appropriate for a learning experience.

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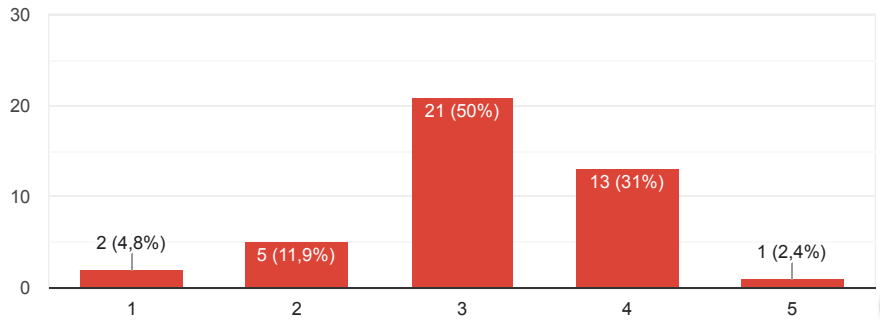
41 respostas



35 - The simulations in this augmented reality app are useful to practice the real-life cases before performing them on the real lab.

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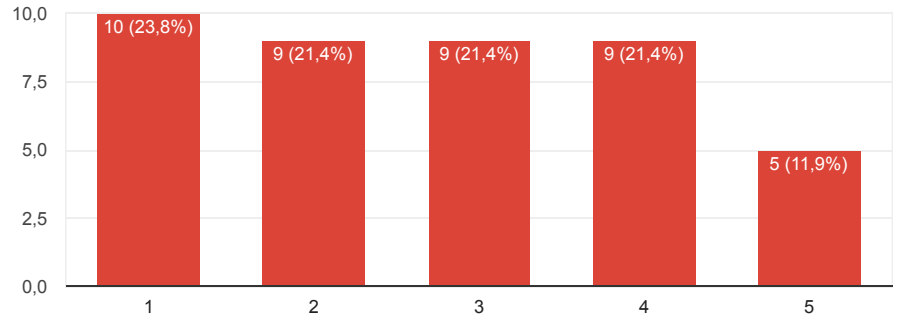
42 respostas



36 - This augmented reality app presented real-world problems through simulations.

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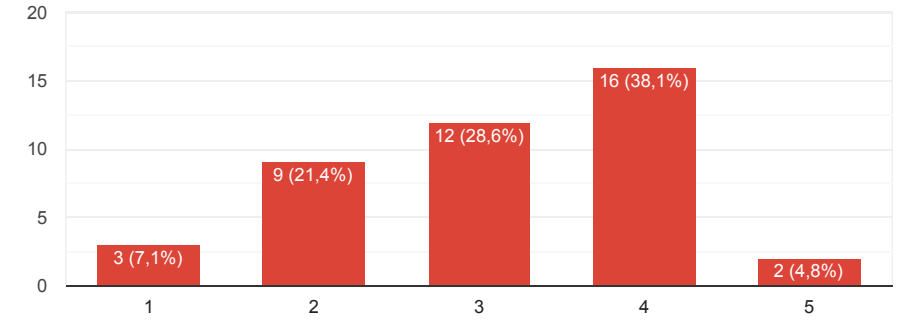
42 respostas



37 - I like to use this augmented reality app in my hands -on training.

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42 respostas



O que achou

41 respostas

resposta de dupla

sem comentários

quando apertamos os botões ele demora para responder

tive um pouco de dificuldade para entender o s personagens no inicio mas depois que pude entender o aplicativo de RA, achei interativo e ludico, vejo grande potencial nesse projeto.

O aplicativo é facil e prático de se usar e tambẽm é facil de se compreender o conceito do jogo.

poderia adicionar inimigos no caminho

resposta em dupla

a interface do jogo é intuitiva so que tem hora que o jogo falha.

Eu gostei da ideia do jogo, acho que deveria ser aprimorado, pois as vezes se torna dificil fazer os movimentos. Mas de resto esta muito top.
(houve anotações dos tempos de cada fase)

Eu acho que deveria melhorar um pouco a textura do mapa e objetos. Deveria ter a opção de configuração, para melhora a experiência dos usuarios, em seus dispositivos.

acho que a identidade visual do icone do aplicativo nao me agrada, e tbm não acho atraente. Em relação ao audio, acho que poderia ou tirar no momento do jogo e deixar somente na interface, ou mudar a musica, deixando o jogo em si com uma musica diferente da intereface. precisam melhorar os recursos oferecidos(rampa,tunel,ponte e escavar).

teve alguns bugs ao jogar como movimentações.a interface é agradavel. graficos sao interessantes. ficamos irritados ao apertar os botoes, descobrimos que nossos dedos eram finos demais para o jogo entender. o objetivo faz sentido.

gostamos bastante do jogo, apesar de uns bugs de renderização, mas rodou liso, bem divertido.

no avançado da erro quando voce faz a rampa e depois faz a ponte ele nao anda e tambemnao consegui fazer o tunel.

Colocar personagens e novas fases

teve problema com as setas de direções, imagi talvez seja por conta do formato delas.

Não consegui subir a rampa, poderia ter como editar o mapa e os personagens, a musica é legal, mas com o tempo jogando , ela fica enjoativa.

em um momento em que eu estava jogando nao sonsegui me mexer, nao sei se for por traz de foi algum erro meu. Ele poderia ter instruções na tela inicial, poderia ir ensinando o jogador as regras.

foi muito dificil fazer o personagem andar pois tinha que tampar o quadrado de interação inteiro, mas fora isso, o jogo é bem legal, interativo e deixa a gente intertido.

Precisa melhora pois quando aperta o botão , demora bastante para responder

sem comentário

melhorar a movimentação do personagem, adicionar obstaculos e mais fases, além de um sistema de ranking para comparar os tempos.

para clicar para o boneco se mexer foi dificil

sem comentarios

melhorar o design dos bonequinhos, aumentar os bonecos ver como fazer as pontes os itens funcionam com mais facilidade.

o reconhecimento da camera e o cenario sao muito bons mas apertar os botões é meio dificil

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