TAL TECH

TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Electrical Power Engineering and Mechatronics

ROBOTICS AND AUTOMATION E-COURSE DESIGN AND VIRTUAL REALITY LEARNING SUPPORT APPLICATION DEVELOPMENT

ROBOOTIKA JA AUTOMAATIKA E-KURSUSE DISAIN NING VIRTUAALREAALSUSEL PÕHINEVA ÕPPIMISE TUGIRAKENDUSE ARENDUS

MASTER THESIS

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Tallinn 2020

AUTHOR'S DECLARATION

Hereby I declare, that I have written this thesis independently.

No academic degree has been applied for based on this material. All works, major viewpoints and data of the other authors used in this thesis have been referenced.

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Department of Electrical Power Engineering and Mechatronics
THESIS TASK

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Main speciality: Mechatronics

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Thesis topic:

(in English) Robotics and Automation E-Course Design and Virtual Reality Learning Support Application Development

(in Estonian) Robootika ja automaatika e-kursuse disain ning virtuaalreaalsusel põhineva õppimise tugirakenduse arendus

Thesis main objectives:

1. Analyze how e-learning environments and VR/AR applications can create an effective synergy in education, especially in the field of robotics and automation.

2. Create an e-learning environment design that fuses effectively with virtual reality, based on the conclusions of the analysis performed.

3. Design and development of a VR application for the MILAN project e-course in robotics and automation.

Thesis tasks and time schedule:

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2.	Breakdown of the problem	07.10.2019
3.	Information search, literature review and analysis	22.12.2019
4.	Conclusions of the analysis of literature review	05.01.2020
5.	E-learning environment design	25.02.2020
6.	VR app design and development	22.04.2020
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CONTENTS

PREFACE

The idea for this thesis topic originated from the participation of Tallinn University of Technology in the MILAN international research project, subsidized by the European Union. This European project aims to elaborate an innovative training course in the field of Virtual Reality (VR) and Augmented Reality (AR) usage in the education of Robotics and Automation. This work was developed at Tallinn University of Technology, Tallinn, Estonia, as the author's graduation thesis for the Mechatronics Master Programme (MSc. in Engineering). The topic was offered by the Mechatronics and Autonomous Systems Centre of TalTech.

The thesis is focused on (1) an initial analysis on how e-learning environments and VR/AR applications can create an effective synergy in education, with an emphasis in the field of robotics and automation, (2) the creation of an e-learning environment design that fuses effectively with virtual reality environments and (3) the design and development of a VR application for the MILAN project e-course in robotics and automation.

The cross-platform game engine Unity was used to develop the virtual reality environment. In addition, the integrated development environment Microsoft Visual Studio, as well as the programming language C# were utilized to create the app.

I would like to express my gratitude to Prof. Mart Tamre, who guided and assisted me on my path to graduation.

This thesis is dedicated to my parents and especially to Teele Anette Koger, for her constant support, help and advice.

1. INTRODUCTION

1.1. Overview

E-learning is the instruction delivered through electronic technologies that supports learning. It usually utilizes media such as images, audio, video recordings and other e-resources to deliver knowledge [1].

E-learning has been massively adopted in the education sector, especially in higher education. It offers students a wide variety of learning resources in different formats (e.g. text, images, audio, videos, animations) through the Internet. This system enhances self-paced learning and eliminates geographical constraints. The increase in research during the last years, has given a better understanding of the critical factors for success in e-learning. However, there is still a lot of room to investigate the quality factors that determine the success of e-learning and its combination with different emerging technologies [2].

Emerging applications, such as Virtual Reality (VR) and Augmented Reality (AR), have the potential to revolutionize the way students explore, interact and learn about new topics [3]–[5]. AR learning environments allow users to view digital data displayed on top of the physical world through technological devices [3], [6]. Virtual reality can provide simulated environments while augmented reality enables users to interact with both virtual objects and elements of the physical world [6]. Smartphones and tablets can work as platforms for AR and VR applications, thus being a familiar device that can introduce the new technology approaches to students [3]. In addition, VR and AR learning environments provided by smartphone-based mobile applications have been previously praised for their tremendous potential in education [7]. VR with head mounted displays (HMDs) has been proven more effective for immersive user experiences [3].

When comparing VR and AR for learning purposes, the sense of immediacy was reported as higher for the students utilizing AR [6]. However, VR has been described as more engaging through the psychological mechanism of spatial presence and more effective to emphasize content that is visually communicated [7]. In [3], results show that VR applications can be effectively integrated for learning purposes. AR applications have also been previously reported as an effective tool to attract students' attention and enhance their concentration towards practical tasks [4]. Furthermore, usage of VR and AR technology has helped students to significantly better understand diverse concepts in science fields, as reported in previous studies [5], [7]. Nevertheless, several studies

have proven virtual reality to be a very effective tool in the fields of robotics, automation, manufacturing and industrial safety practices [70], [86], [87], which is why this technology was prioritized in this thesis over AR.

Despite the potential of both technologies, nowadays most students and teachers are still unfamiliar with the use of VR and AR since these applications still represent a rare and relatively new tool in education [3]. Although VR and AR have been recently described as powerful tools to improve the students' knowledge construction and learning experience [3]–[7], a deeper understanding of the impact of this technology in learning is required [3]. VR and AR usage in education is still in a very early stage and continues to represent a very underexplored topic which needs more research studying its use in different educational fields [3], [7], [8].

1.2. Problem statement

The problem statement can be described as follows:
It is not clear how VR/AR applications can be effectively combined with e-courses for learning purposes, with a special emphasis in the field of Automation and Robotics.

The problem is currently researched by the international MILAN project, an initiative directly addressed to the Erasmus+ call 2018 Horizontal priority "Open and innovative practices in a digital era". The project activities are directed to the elaboration of high-quality, open and innovative training materials and tools in the field of Robotics and Automation with the support of Virtual and Augmented Reality [9]. The MILAN project must develop an innovative training e-course in the field of Automation and Robotics combining VR and AR to support the adoption of the course materials. This work intends to be a contribution to the research. In the second chapter of the thesis, the impact of virtual and augmented reality in education is analyzed. After the analysis, virtual reality is selected as the most optimal technology for this work, based on evidence from previous research [70], [86], [87].

1.3. Objectives of the research

As explained in section 1.1 (Overview), more research is currently necessary to understand how the combination of e-learning courses and VR/AR applications can work

together effectively. As further presented in the thesis, the main objectives of this work are:

1. Analyse how e-learning environments and VR/AR applications can create an effective synergy in education, especially in the field of robotics and automation.
2. Create an e-learning environment design that fuses effectively with virtual reality, based on the conclusions of the analysis performed.
3. Design and development of a VR application for the MILAN project e-course in Robotics and Automation.

The research question being addressed can be summarized as follows: How VR/AR applications can help students to better adopt the materials in Automation/Robotics and other e-learning courses?

1.4. Motivation

The author of this work has a strong personal interest in teaching methodologies as well as in e-learning and emerging technologies to enhance students' academic performance. In addition, the author believes that it is key to recognize that the most important part of an e-learning environment is the content and its educational value. VR and AR applications are merely tools to achieve the objectives of a course. They must help to deliver the contents and enhance the learning experience. The emphasis should be put in the first place on the design of the e-learning course, the learning materials, the explanations, examples and tasks. In brief, placing learners' needs as the top priority and maximizing the value given to students. Once the overall design is robust and consistent with learners' needs, technologies and tools can be utilized to add quality.

1.5. Results of this work and their significance

The work output is an e-learning environment design that can be adequately combined with virtual reality, as well as a VR application directly related to robotics and automation. This work is expected to be used as a solid base for present and future e-learning courses.

2. DEFINITION AND ANALYSIS OF THE PROBLEM

2.1. Breakdown of the Problem

In this chapter, the problem will be defined and analyzed. The first principles thinking methodology will be followed. The application of first principles and systematic thinking constitute the foundation to achieve design engineering expertise [10].

First Principles thinking allows designers and engineers to identify their assumptions over a given problem. Once all the assumptions are enumerated, each of them must be questioned. Fundamental yet powerful questions must be asked. Answering these questions helps to breakdown the problem into its fundamental principles (the most fundamental truths). Once these principles are found, it is possible to create new solutions built from the fundamental truths. The methodology enables engineers to solve specific problems from scratch [10].

The question being addressed in this thesis can be summarized as follows:
How can VR/AR applications help students to better adopt the materials in Automation/Robotics and other e-learning courses?

Therefore, the problem statement can be defined as follows:
It is not clear how VR/AR applications can help students to adopt the materials in the MILAN project e-course of Automation and Robotics as well as in other e-courses.

Table 2.1 includes the most critical elements identified in the problem statement.

Table 2.1. Critical elements of the problem statement

Element
VR
AR
Students
Learning
Automation
Robotics
E-learning environments

Based on the problem statement and its most important identified elements, the assumptions of the author of this work on the topic were identified, which are shown in Table 2.2.

Table 2.2. Author's assumptions on the topic

		Author's Assumptions
Element	**Learning**	Video lectures are better than in-classroom lectures because learners can stop the explanation and rewind it as many times as needed
		Learning visually and audibly through images, videos and animations is the most efficient way to learn nowadays
	E-learning environments	E-Learning environments certainly help students to better learn course materials
		E-Learning platforms are better than traditional classroom systems
		Learning online is significantly better than traditional in-classroom learning when it comes to giving students the possibility to study when and where needed
		E-Learning gives the opportunity to continue learning through a mobile app anytime and anywhere
	Students	Students are more motivated to complete their studies when they must physically attend lectures and practices
	VR	VR applications enhance the learning experience for students
		VR applications are tedious to use because they need bulky and expensive head mounted displays
	AR	AR applications help students learn new topics since they can immediately comprehend information visually
	Automation/ Robotics	Robotics and Automation are difficult learning fields to teach online since they often require the utilization of physical components and hardware
		Automation and Robotics fields involve abstract and complex concepts that have great potential to be explained through visual content

Once all the assumptions were identified, a series of questions were formulated in order to decompose the assumptions and find the fundamental principles to build from. This process can be somehow compared to the Methodic doubt in Cartesian Philosophy, which searches for certainty by systematically doubting everything [11]. Table 2.3 contains the questions addressed to uncover the most fundamental principles.

Table 2.3. Formulated Questions to uncover the fundamental principles

		Questions
Element	**Learning**	- What is learning? - Why do humans learn? - How do humans learn?
	E-learning environments	- What is e-learning? - Can e-learning help students to better gain knowledge? - What are the pros and cos of e-learning environments and other learning approaches when they are compared? - What are the main features of other currently successful e-learning platforms?
	Students	- Who is the target audience of the course? - What factors make students succeed in fully completing a course? - How to build effective study habits in students?
	VR/AR	- What are VR and AR applications? - How VR and AR applications help students learn?
	Automation/ Robotics	Which Automation/Robotics topics can be combined with a VR/AR application?

Answering the questions shown in Table 2.3 will allow to expose the first principles. Based on those, the solution will be built. In the next sections, answers to the questions are provided.

2.2. Learning

2.2.1. What is learning?

The concept of learning has been a critical research topic since psychology emerged as an independent science. Nevertheless, researchers and authors of influential textbooks on learning are generally not explicit about what they mean when the term learning is utilized. Even today, there is no general consensus about the definition of learning, since it is a broad and abstract concept. In spite of the definitional issues, learning researchers and experts seem to have a clear sense of what learning is [12].

One common functional definition of learning given by many textbooks is that learning is a change in behavior due to experience [13]. However, many researchers have found this definition of learning unsatisfactory for its simplicity [13]–[15]. In [16], it is argued that not all change in behavior means learning. Learning is therefore described as the

more or less permanent changes and reinforcements caused voluntarily in an individual's pattern of acting, thinking and/or feeling.

In [12], learning is rather defined as "changes in the behavior of an organism that are the result of regularities in the environment of that organism". In this case, all types of behavior are seen as responses to the environment, therefore linking changes in behavior to the presence of different current or past stimuli. This definition includes the concept of regularity, referring to the repetition of a single stimulus at multiple moments in time or to the repetition of multiple stimuli at a single or at multiple moments in time.

According to [17], learning is a natural process that continues through life, associated with practical physical or intellectual experience. This definition explains that individuals learn physical or intellectual skills through their lifetime by practicing them repeatedly, since it is reported that experience comes with practice.

Following the definition of [18], learning is a process that leads to change, occurring as a result of experience and enhances the potential for improved performance and learning that may take place in the future. It is emphasized by the authors that (1) learning is a process, not a product and learning occurs from individuals' products or performances, (2) learning involves change in knowledge, beliefs, behaviors or attitudes and (3) learning is not something done to individuals, but rather something individuals themselves achieve. It is the consequence of how individuals respond to their experiences (conscious, unconscious, past and present).

Although there are differences between these definitions, it is possible to extract from them that learning is a process that produces change in behavior due to experience which enhances the potential for improved future performance. In this definition, behavior is understood as an individual's pattern of acting, thinking and/or feeling and experience as the familiarity with a skill that comes from practice repeated over time.

2.2.2. Why do humans learn?

The theory of evolution [19] developed by Charles Darwin explains how species evolve driven by adaptation to the environment. Evolution theory mainly studies phylogenetic adaptation (the adaptation of species to the environment for generations), while learning psychology studies ontogenetic adaptation, which is the adaptation of individuals to the environment during their lifetime [12]. According to this definition, a

way to understand why humans learn can be understood as an instinct to survive. Individuals need to adapt to their environment to stay alive. The need to adapt leads to learning, produces changes in their behavior. With this approach, it is therefore possible to conclude that individuals are forced to adapt and learn due to external changes in the environment that they cannot control.

Other perspectives given by [17] involve the desire to learn in order to obtain an outcome out of learning. For instance, learning can satisfy the desire to understand the world in which individuals live. Other individuals may be driven by the desire to obtain an income (by trading certain skills they have previously learned). Others may desire to learn about a topic because they have passion for it. In all these cases, learning is driven by a specific goal that is triggered by a certain desire. In addition, in [18], it is stated that a goal-directed practical approach blended with targeted feedback increases the learning experience and quality for students.

From [20], another perspective can be extracted. In this study, views from different students of secondary school are given. Many of the testimonials shown in the paper describe learning as something imposed. The learning system was described as an "oppressive, suffocating system" and students reported to "feel forced to learn things against their wish". In this case, learning is described as a consequence of individuals being forced to learn something.

In Table 2.4, the different reasons that lead to learning are shown in three different categories. This work is going to focus on goal-driven learning, since students will be free to choose to study the materials of the MILAN project e-course or not. In the case of the MILAN project, learners may have different desires that define their goal or goals, and these will ultimately lead them to learn about Robotics and Automation in order to accomplish them.

Table 2.4. Types of learning

	Description
Learning led by survival instinct	Learning happens in order to adapt to the environment changes and survive
Goal-driven learning	Learning happens in order to achieve a certain goal, triggered by desires
Imposed learning	Learning happens because individuals are forced to learn something

2.2.3. How do humans learn?

All humans, unless they are afflicted with certain organic problems, are born with an immense capacity to learn [21]. During the first years of life, humans learn more than in all the remainder of their life. New-borns start to learn since the day they are born and continue to learn until they reach the end of their life [17].

One way individuals learn is by trial and error. This approach is more centered in research and discovery. Once a correct solution has been found by trial and error, strengthening the knowledge on it can be achieved with practice (repetition over time) [17], [22]. A person could try to learn first the theoretical part of a certain task and then put it into practice. However, it is important to note that in this case, both theoretical and practical parts will need repetition. An individual who applies several repetitions to learn the theoretical part of a problem will likely strengthen the knowledge more than an individual who has applied less repetitions (and has not put it into practice yet). The choice to spend more time learning theoretically or practically is a matter of preference. And in this case, regarding preferences, it is important to distinct between different learning styles [17].

While it is evident that individuals differ in how they prefer to learn, the educational implications of such preferences have been a source of controversy among researchers and educators [21] as cited in [23]. Learning styles assessment in instruction is proposed by authors who believe that learning styles can be identified and utilized to enhance the learning experience of students [24].

Kolb's learning inventories [25], [26], are the most widely utilized learning styles in research [27]. Kolb identifies a four-stage cycle for learning. He describes that the learner starts with the first stage (Concrete experience), where the learner does something. Then, the second stage takes place (Observations and reflections), where the learner thinks or reflects upon what he or she has done. In the third stage (Formation of abstract concepts and generalizations), the learner speculates about diverse actions, and in the fourth stage (Testing implications of concepts in new situations), the learner experiments and tries something new. However, Kolb admits that something as complex as an individual learning style is a combination of at least two of the four learning stages. Therefore, he classifies learners into four categories: divergers who prefer feeling and observing (concrete, reflective), assimilators who prefer thinking, conceptualizing and watching (abstract, reflective), convergers who prefer conceptualizing, doing and experimenting (abstract, active), and accommodators who prefer feeling and experimenting (concrete, active) [17], [25], [26].

Although Kolb's classification is mostly used in research, the VAK/VARK learning styles classification is the most common used in practice [27]. The VAK classification groups learners into visual/auditory/kinesthetic while the VARK classification categorizes learners into visual/auditory/read–write/kinesthetic. This categorization is generally associated with Fleming [27]. Information about the VARK model [27]–[30] is shown in Table 2.5.

Table 2.5. VARK learning styles

	Description
Visual	- Learns through demonstration and description - Easily distracted by movements or actions but not by noises - Prefers to use animations, videos, 3D models, figures, pictures, and symbolic tools such as graphs, flowcharts, hierarchies, models and arrows - Explains concepts to others by making drawings - Rich in imagination and creativity
Auditory	- Learns by listening and speaking - Puts attention to the words expressed by the instructor - Prefers to listen and later discussing topics than writing lecture notes - Listens to recordings of a topic in order to learn and strengthen their memory - Utilizes loud reading and repetition to remember information - Teaching other people and discussing topics with instructors strengthens their understanding and memory - Expresses concepts and ideas easily
Read-write	- Prefers reading texts as a method to learn - Likes lists, glossaries, textbooks, lecture notes, or sketches. - Takes notes and tend to paraphrase them - Prefers to study through lecture notes than from other reading materials
Kinesthetic	- Learns through a combination of different sense functions - Prefers learning that comes with hands on work, projects, real experience and practice - Likes to touch, experiment and interact in order to learn - Dislikes gaining information only by watching or listening - Tends to think while physically moving - Utilizes movements to better remember

	- Kinesthetic learning can enhance students' motivation towards learning

Many authors report that these are general categorizations and learners can belong to different groups and their categories may also change over time [17], [25], [26], [31]–[34]. In addition, adequate learning not only depends on students' learning style, but also on the teaching materials utilized. Therefore, a big emphasis should be put in the production of teaching materials considering the students' learning styles [29].

In [31], it was found that 61% of students had multimodal learning style preferences and that only 39% students had unimodal preferences. Amongst the students who preferred multimodal learning styles, bimodal was the most favored with 41%, followed by trimodal with 14% and quadmodal with 6%, respectively. In [32], 52% of students were grouped as having preferences for multimodal learning styles, with half of these students (about 26%) categorized as having quadmodal preferences. According to [33], it was found that 70.3% of individuals had multimodal style preferences with 35.8% of learners sharing all four learning style preferences while individuals with a single learning style preference represented only 29.7%. In addition, in [34] learners with a multimodal set of preferences represented 63.7% and those with unimodal preferences represented 36.3%.

Another study found that students from Mechatronics Engineering mostly preferred multimodal learning style (29.2%), followed by unimodal learning styles: Auditory (20.8%), Kinesthetic (16.7%), Reading/Writing (16.7%) and Visual (16.7%), showing that learning style preferences are very close to each other within Mechatronics students [35].

According to [34], in the 2017 June to December database (n=170653), of the total options chosen, 28.6% were for Kinesthetic, 25.8% were for Auditory, 23.7% were for Read/write and 22.0% were for Visual. However, looking only to those in the field of Engineering, the results vary slightly: 29.4% for Kinesthetic, 24.6% for Auditory, 24.0% for Visual and 22.0% for Read/Write. Also, in this study it is reported that when reducing the comparison to the four modes only, 37.5% of those respondents had Kinesthetic as some part of their profile: Kinesthetic appeared a single preference or as part of their bimodal or trimodal preferences (AK, RK, VK, VAK, ARK or VRK). This shows that learners have a clear tendency towards the Kinesthetic approach (hands on work, real experience, practice and experimentation).

Many studies suggest that effective learning is caused by teaching methods that include a blend of activities for visual, auditory, read-write and kinesthetic modalities [24], [31], [34], [35]. However, certain authors warn that there is no clear evidence that learning styles help to improve the overall learning experience of students [21], [27]. Nevertheless, as pointed by Cuevas in [27], the learning style hypothesis cannot be considered as debunked, addressing the need for more experimental research in order to find certainty.

Motivation has been reported by several authors as a key factor to maintain and enhance in the students' learning process. Motivation in students is critical in leading the direction, constancy and intensity of learning [18], [22], [29]. Motivation is also linked to the social, emotional and intellectual side of students. The climate of the course must be designed for a positive social, emotional and intellectual experience in students. While a negative climate can obstruct learning, a positive climate boosts performance and learning [18]. In addition, motivation is linked with rewards. When individuals perceive that positive rewards are associated with the adoption of knowledge, they are more stimulated to continue learning, and the overall experience is enhanced. Thus, the utilization of rewards as a method to increase the learners' motivation is critical [36].

Memory is considered another critical factor that influences learning and it is clearly linked to the concepts of practice and repetition [37]. Memory is the faculty of the brain to store information and retrieve it when it is necessary. The three stages in memory are classified in immediate, short-term and long-term memory [17].

Immediate memory can gather and keep data during seconds, such as streets passed in a car while driving around in a city. Short-term memory retains information long enough to utilize it for a certain purpose, such as reading a phone number and remembering it long enough to perform a call. Short-term memory duration is limited, and only small amounts of data can be retained. In addition, it can be easily disturbed by distractions or other stimuli. When information stored in short-term memory is repeated over time, it becomes part of the long-term memory [17]. Without practice and repetition, information is forgotten [37]. Forgetting appears due to the limited capacity of short-term memory to store data, erasing the retained information and replacing it with new one. Long-term memory stores and retains data for long periods of time, that go from months to an entire lifetime. Improving memory through association has been proven effective: for instance, memories can be associated with songs, sights, tastes or smells from personal experiences. What is stored in the long-term memory may be available for extended periods of time, but not necessarily

accessible. For example, meeting someone but not remembering his or her name. It is noteworthy that memory combined with association helps to reduce the effects of this phenomena and helps to improve the access to long-term memory [17].

In order to increase the efficiency of learning and help students learn and store the information in the long-term memory, practice and repetition must take place [38]. Ebbinghaus' curve shows the relationship between memory and time [39]. Figure 2.1 (obtained from [38]) represents Ebbinghaus' curve.
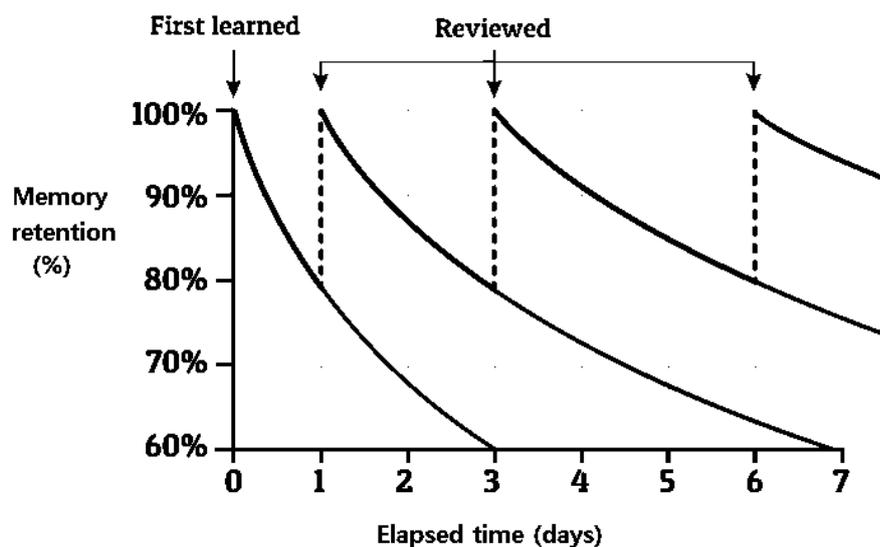

Figure 2.1. Ebbinghaus' forgetting curve and the effects of reviewing with spaced repetition [38]

Spaced repetition shown in Figure 2.1 minimizes the forgetting effects and helps individuals remember for longer periods of time. There have been many proposed spaced repetition algorithms [37]. In [38] it is suggested to review what has been learned four or five times. right after a lesson, in the evening, one week later, and one month later. According to [40], the optimal gap between the first and second reviewing sessions increases depending on how far away the examination is. So, for example, if the exam is one week away, the first study gap (period of time between first and second sessions) should be one or two days; if the exam is one month away, the first study gap should be one week; if it is three months away, it should be two weeks; if it is six months away, it should be three weeks; and if it is one year away, it should be one month. It is important to note that these gaps are approximations since there is no clear consensus on what algorithm performs better.

2.3. E-learning environments

2.3.1. What is e-learning?

E-learning is the instruction delivered through a digital device (such as smartphones, tablets or computers) that supports learning [1]. E-learning involves in many cases the utilization of media (such as images, audio and video recordings), and other materials. In its early years, these resources were shared in shared disks but nowadays it is common to use them online. Thus, e-learning is also known as online learning.

At the present time, learners must have diverse problem-solving, decision-making skills and creativity. In order to accomplish these goals, education has undergone a big transformation towards e-learning, allowing information to be sought when and where needed [41]. So, essentially, with e-learning, users can adopt new information and gain knowledge by having access to didactic resources and activities held by the instructors online, eliminating time and location constraints [42].

2.3.2. Can e-learning help students to better gain knowledge?

According to [22], the effectiveness of e-learning has dramatically increased in the previous years. In this study, is was found that resources provided, support to learners, students' motivation, previous experience and interaction between the e-learning environment and the users, all are critical for effectiveness. In order to design an optimized and effective e-learning environment, the following features must be taken into consideration [1], [43]:

- It stores and provides the materials in electronic form available when and where needed.
- The materials and content are directly relevant to the learning objectives.
- The goal or goals to be accomplished in the e-course and the progress made to complete them are always clear to learners.
- Media content is utilized, such as pictures, animations, video lectures, 3D models, simulations, e-textbooks, etc.
- Methods of instruction such as examples and systematic tasks to put the knowledge into practice are used.
- Feedback is continuously given to students.
- Forums or other spaces open to discussions are available.

- The designed e-learning prioritizes the needs of the individual learners (users) rather than prioritizing the instructor's or educational institution's needs.

A total of 56% of previous studies that were analyzed in [22] defined effectiveness as 'learning outcome' and applied this definition, and 38% of the them utilized the definition of 'transfer (application to practice)' and applied it. 'Learning outcome' refers to measuring the individuals' learning through assessment methods, such as using a pre-test, final examination (post-test) and a final grade. In 'transfer (application to practice)', the ability to apply the content provided in the e-learning platform is essential, sometimes assessing effectiveness with the learners' self-assessments (satisfaction, individuals' effort, reported changes in practice, etc). The first approach shows the importance of measuring the students' performance through time in order to control (and redirect if necessary) their progress. The second approach stresses the importance of putting what is learned into practice to enhance the learning experience.

Previous experience of participants can increase of decrease effectiveness, which was emphasized in [18], [22]. The effect of gender disappears in Web-based courses. If previous knowledge is not built upon strong foundations, it can hinder the individuals' learning progress [13]. Previous works have found e-learning effective in delivering knowledge [1], [22], [41]–[45]. From all the studies analyzed in [22], only 10% of them found e-learning not to be effective, so the answer to the question addressed is affirmative: e-learning effectively helps students to gain knowledge. In item 2.3.3, e-learning is compared with other types of learning in order to reveal its upsides and downsides.

2.3.3. What are the pros and cons of e-learning environments and other learning approaches when they are compared?

E-learning has gained popularity in recent years; however, it is important to also consider what are the strengths and weaknesses of it and other learning approaches. Traditional learning involves in-classroom delivery of knowledge, having both geographical and time constraints. Many studies have reported that e-learning has provided better results than traditional learning [46]–[48]. Nevertheless, other studies do not agree with these findings. For instance, in [49], no significant difference was found in the final exam scores of the individuals in online and traditional learning. Also, other researchers have stressed the importance of social aspects as well as interaction

with the instructor in learning. As reported in [22], learning and active participation in online discussions was enhanced by social interaction with instructors as well as with collaboration with peer students. In addition, the success rate was found higher among students in e-courses that were led by an instructor than e-courses with independent-study styles. The opportunities that online learning gives individuals to cheat were described as much higher in online learning than traditional learning in [49]. In the same study, the advantages and opportunities of these students to cheat were minimized by adding an in-campus supervised environment to take the exams for online students. This approach to combine elements of e-learning and traditional learning is the essence of 'blended learning'. The idea of blended learning is attractive since it maintains elements of traditional learning which are effective and it includes many advantages of e-learning [50]. Different studies [41], [42], [46]–[52] were utilized to assess and complete Table 2.6. It compares the three learning approaches and manifests their advantages and disadvantages. The different approaches are evaluated with a score from 1 to 5 (1 corresponds to 'very low correlation'; 2 corresponds to 'low correlation'; 3 corresponds to 'normal or medium correlation'; 4 corresponds to 'high correlation'; 5 corresponds to 'very high correlation').

Table 2.6. Advantages and disadvantages of different learning approaches

	Traditional in-classroom learning	E-learning	Blended learning
It is easy to include different individuals' learning preferences and learning styles	3	5	5
It enables students to always keep track of their current progress (where they are and where they should be)	2	5	5
It gives flexibility to learners in terms of place and time	1	5	3
It is cost-effective for both learners and instructors	2	5	3
It continuously gives students a clear picture of the goals to be accomplished	3	5	5
It stimulates students' interaction and participation in discussions	4	3	3
It enables learners to easily put the new	4	3	4

knowledge into practice			
It enhances social interaction and reduces isolation	5	2	3
It boosts the learners' communication skills	5	2	3
It reduces the opportunities to cheat	5	2	5
It enables individuals to quickly clarify their questions	5	3	4
It increases students' motivation	2	4	4
It increases feedback quantity and quality	3	3	4
Total	44/65	47/65	**51/65**

As shown in Table 2.6, the best result is obtained with blended learning with 51 points out of a maximum of 65, followed by e-learning with 47 points and lastly 44 points for traditional in-classroom learning. This result is meaningful since it shows how the synergy of e-learning and traditional learning can give students the best learning experience. Moreover, this idea matches with the conclusions of previous studies that utilize and suggest diverse approaches for effective blended learning [50], [53], [54].

Nevertheless, in a fully taught e-learning system, some of the benefits of other approaches can be adopted by thinking of new ideas to design the platform. Table 2.6 enables the designer to identify the features that must be improved for each approach and brainstorm new ideas to enhance the overall learning quality.

2.3.4. What are the main features of other currently successful e-learning platforms?

Several large international online e-learning platforms have been analyzed (Udemy [55], Pluralsight [56], Udacity [57], edX [58]). The main features of each of them are highlighted in Table 2.7. These features can be utilized to later generate a more appealing e-learning environment design.

Table 2.7. Analyzed online e-learning platforms and their main features

		Main features
E-learning platforms	Udemy	- Courses organized by categories - Detailed description of courses plus "What you will learn" and "Who this course is for" information - Course requirements information - Information on selling rates for each course - Customer average rating and number of ratings for each course - Number of students enrolled in each course - Emphasis in the certification of completion - Information about what the course includes (resource types, practice tests, access type and certification) - Resources given in video and text format - Information about language of instruction and subtitle options - Big discount offer $199 to $9,99 (commonly available) - Affordable prices in many courses ($9,99) - Featured reviews shown in each course - Course contents information and contents preview - 30-Day Money Back Guarantee emphasis - Instructor's rating, reviews and qualification for each course - Students' feedback comments in each course - Focused in very different fields of knowledge
	PLURALSIGHT	- Path organization of courses: Complete selection of courses to take each student from novice to expert - Organization of videos in each path by beginner, intermediate and advanced level - Information about the number of hours needed to reach expert level - Information about "What you will learn" for students - Pre-requisites information in each path - Course description - Table of contents for each course - Course overview in video format - Average customer rating and number of ratings - Information about the instructor - Skill and role tests available to consumers to understand where they are and where they are going - Price per month, 6 months or 1 year to access the platform - 10 days free trial to use the platform - Focused only on ICT related courses
	UDACITY	- Organized by fields of knowledge - Presentation of courses as nanodegrees - Advertising nanodegrees as a path to a new career or to a better job - Estimated time to complete them require several months (information of months and hours per week required are given)

		- Pre-requisites information
		- Information of companies in the field that they partner with
		- Registration period, start and finish dates are set from the beginning
		- Nanodegrees only available for limited periods of time
		- Information about "What you will learn" for students
		- Information about program contents
		- Personalized feedback is given to students
		- Individual 1-on-1 mentorship
		- Previous students reviews available for the programs
		- Only high-ticket products available ($199 per month or $1074 for every 6 months)
		- Courses focused on ICT, AI, Automation and Business
	edX	- Organized by fields of knowledge
		- Courses are designed by recognized institutions
		- Courses overview in video format
		- Courses start on a specific date
		- Course description
		- Information about "What you will learn" for students
		- Information about the instructors and their qualifications
		- Only selected learner testimonials are shown
		- Frequently asked questions section for each course
		- Information of weeks and hours per week required are provided in each course
		- Courses are offered for free with the option to obtain a verified certificate for a price
		- Information about the institution providing the course is given
		- Language and transcript options are shown
		- Pre-requisites are shown to students
		- Platform is focused in very different fields of knowledge

2.4. Students

2.4.1. Who is the target audience of the course?

According to the information provided by TalTech website [59] and the MILAN project website [9], the project target groups are:

- People employed at SMEs: workers operating advanced machines (robots, automats, assembling cells/machines) as well as middle-level technical staff.
- Teachers/trainers/consultants in the field of Robotics and Automation.
- Students of vocational schools.

As pointed in the MILAN project website [9], it is an online e-learning course. This means that students will access the platform and the materials through the internet. This clearly defines a key element to consider: The access of the virtual reality or augmented reality app must be provided to students at anytime, anywhere and without the need to purchase expensive equipment.

2.4.2. What factors make students succeed in fully completing a course?

According to [60], there are several factors that influence academic achievement of students. The most highlighted individual attributes were 'sense of accomplishment' (learners notice the progress at each moment in time and perceive new gained skills), 'mastery of skills' (learners feel very confident and capable to put the new knowledge into practice), 'perceived utility of learning' (learners understand how that knowledge can be useful to them) and 'meeting career goals' (individuals clearly see how the learned information will help them meet their specific goals).

In [36], the final factor influencing student persistence was dependent on the number of hours of virtual system usage. Also, according to [61], regular study was the strongest predictor of academic achievement. Other factors previously reported include ease of use and usability of the system, feeling of connection with the institution delivering the content and collaboration with peer students [36]. Late submissions and not reading the course information packets also predicted individuals' poor performance [61]. Student Success Courses (SSC) provide learners with information about the institution they attend, techniques to develop effective study skills and habits as well as academic and career planning aid. Results in [62] showed that SSC enhances student engagement, persistence, retention and academic achievement, especially when instructed at the beginning of a program. This reinforces the ideas presented in [36], [60], [61], which encourage instructors to clearly show students where they currently are, what their goals are (where they are going) and how the adopted knowledge will help them meet their goals.

It is possible to observe how regular study can enhance students' academic success. In order to achieve that, learners must acquire the habit to study. Building study habits is further explored in item 2.4.3.

2.4.3. How to build effective study habits in students?

Previous studies have shown the importance of individuals' motivation in academic success [18], [22], [29], [30], [47]. This concept is also outlined in item 2.2.3. In order to create study habits, the learners' must be motivated to learn. However, maintaining motivation through time is not an easy task. Therefore, the Hook Model [63] can be utilized to help students create regular study habits. It is a four-phase process that forms habits in users. Figure 2.3 (obtained from [63]) shows the four phases of the Hook Model.

Before explaining the phases of the model, it is important to understand habits. Neuroscientists have reported that habits enable individuals to store responses automatically in the basal ganglia (area of the brain linked with involuntary actions), while focusing their attention on other things [64]. Habits are created when there is no active deliberation by the brain and a behavior is codified to give a solution to a certain problem [63]. A habit like nail biting is an immediate automatic response triggered by an unpleasant feeling or stress. In order to develop a habit-forming product, two variables must be taken into account: frequency and perceived utility. The more frequency and perceived utility, the stronger the habit. Frequency refers to the amount of times the behavior occurs, which again matches with the findings of [36], [61] as well as with the concepts of practice and repetition described in item 2.2.3. Perceived utility refers to how useful and rewarding the behavior is in the users' mind. Figure 2.2 (obtained from [63]) shows the Habit Zone taking into account frequency and perceived utility.
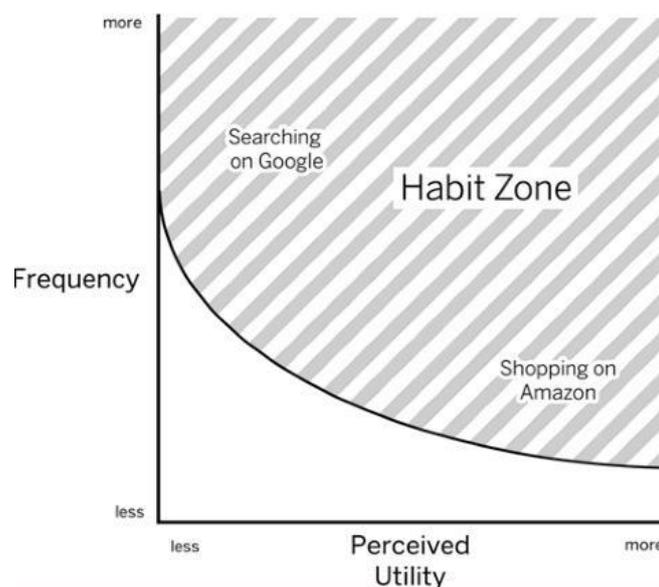

Figure 2.2. Habit Zone [63]

If individuals perceive that their need (learning in this case) is not being solved, they will not continue learning with the program, course or platform. Both frequency and perceived utility must feed each other. The main focus should be put into the value given to the learners, so that they continuously perceive the utility and progress towards their goals [60], [63].

In order to engage learners with their studies, the Hook Model shown in Figure 2.3 (obtained from [63]) provides a clear path. The first phase is the trigger. It is the actuator that starts behavior. Triggers are internal and external. Products that create habits in users begin showing external triggers such as an e-mail, the app icon on a smartphone, a website link or a notification. Yet external triggers are only the first part. The idea is that, after several cycles, users do not need further instigation caused by external triggers. That is the point where individuals are prompted by internal triggers. When a product or service is associated with a thought, an emotion, or a previously developed routine, an internal trigger manifests. The most effective powerful internal triggers are negative emotions, such as frustration, loneliness or confusion, which produce an almost instantaneous action to mitigate the negative emotion. However, positive emotions are also internal triggers. The idea is that the product given to the users must eliminate the pain of users (the negative emotion) so that every time they feel it, they think about using that product. Finally, gradually these repeated actions become habits linked with internal triggers [63].
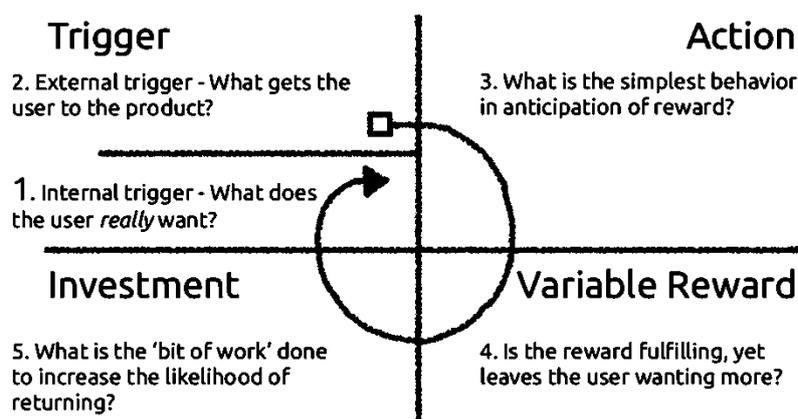
Figure 2.3. The Hook Model [63]

The second phase of the model is Action. As explained in [65], for any action to take place, a trigger must be present while the user has the ability and motivation perform it. In [66], motivation is defined as "the energy for action". The right motivators create action by promising an outcome that the user desire [63]. Ability refers to how easy it is to perform the action. Ease of use is a key factor. The easier, the better [36].

According to [65], simplicity is critical and it is defined by six elements: time (how long it takes to perform the action), money (how much it costs), physical effort (physical activity required to take the action), brain cycles (the mental effort needed to complete the action), social acceptance (level of acceptance of the action by others) and non-routine (degree of disruption of the action with current routines). It is also noteworthy that every behavior is driven by one of the three core motivators: searching for pleasure and escaping from pain, searching for hope and escaping from fear and searching for social acceptance and escaping from social judgement and rejection [63].

Variable reward is the third phase of the Hooked Model. When individuals know that there is going to be a reward after completing an action, motivation is dramatically enhanced [36], [66]. In [63], rewards are classified in three categories: rewards of the tribe (seeking for social rewards powered by connectedness with other individuals), rewards of the hunt (seeking for resources and information) and rewards of the self (seeking for rewards of competence, completion and mastery). Variable rewards increase dopamine level in the nucleus accumbens (area of the brain associated with pleasure). Experiments reported in [67] showed that variable rewards satisfy and maintain interest over time by adding variability.

Investment, the fourth phase of the model involves commitment from the users' side. Individuals that invest more time and effort into a product, value it more. This is part of human nature; individuals overvalue their own work more than others' work. This phase comes after the variable reward is received by the user, when individuals are more likely to put effort [63]. The more time and effort individuals put into something, the more they value it and use it.

2.5. Virtual Reality and Augmented Reality

2.5.1. What are VR and AR applications?

Augmented and virtual reality can change users' perception of the world. Virtual reality brings individuals to a new digital environment, enabling them to interact with it [68]. By using closed goggles, such as Oculus Rift, VR puts users' presence elsewhere [69]. Augmented Reality combines real and virtual objects together, overlaying virtual objects onto the real world in real time [68]. Smartphones, tablets and other smart devices can work as platforms for AR and VR application, thus being a familiar device that can introduce the new technology approaches to students [3]. Both approaches have

advantages and disadvantages depending on the need that must solve. VR has been proven more effective for immersive user experiences [3]. Nevertheless, VR means that users are unable to interact with the physical world [6], something that is possible to do with AR. In the next item, the impact of VR and AR in the field of education is analyzed.

2.5.2. How VR and AR applications help students learn?

Inexpensive consumer virtual reality display technology has brought new opportunities to deliver knowledge and training with immersive and engaging technologies like VR and AR. Virtual learning environments have generated positive learning outcomes in a variety of fields, including education [70], [71]. In [3], results showed that VR applications can be effectively integrated for learning purposes. In addition, AR has been proven effective in learning [72] and it has been described one of the most promising technologies in education in the next years [73]. Moreover, results of previous studies suggest that combining real objects, AR, and VR provides potential benefits in a collaborative, educational environment [74], [75].

When comparing VR and AR in education, VR was reported as more engaging than AR through the psychological mechanism of spatial presence and more effective to emphasize visually communicated content [7]. The great sense of immersion created by VR environments can provide on-site training in a controlled and safe environment [70]. In [76], researchers used VR to introduce the concepts of special relativity in a game like environment. After utilizing the virtual system, students believed that the simulation was a positive learning experience and described the subject area as being less abstract. Results also showed that students performed better in concept tests on special relativity, showing that VR was dramatically useful in making traditionally difficult abstract topics more accessible to learners. Moreover, virtual learning environments can give access to highly expensive equipment in locations that are difficult to access [70], like manufacturing facilities. Also, majority of participants in [77] reported positive aspects of VR, including increased social interactions and reduced social anxiety. Nevertheless, it has been reported that it is not clear how VR would maintain attention and motivation in students through repeated use [3].

On the other hand, students using AR performed significantly better than those using VR regarding learning and task performance [78] and AR provided students with a higher sense of immediacy, as reported in [6]. AR applications have been previously

reported as an effective tool to attract students' attention and enhance their concentration towards practical tasks [4]. Furthermore, usage of AR technology has helped students to significantly better understand complex abstract concepts in science fields, as reported in previous studies [5], [79]. AR has the power to transform academic environments, making them much more efficient, enjoyable, and interactive than before. AR provides excellent possibilities in education, especially in e-learning. With augmented reality, the need to determine the learning contexts and situations will no longer exist, as the conditions of the physical world specify all of them [73], [80].

Designing VR and AR environments for learning must explicitly include pedagogical considerations [81]. To develop effective educational training virtual environments, the designer must begin understanding the learning objectives, re-creating the real-world tasks, and assessing the learner progress as well as his or her performance [70]. Also, in order to design and promising VR environment for learners, a framework that clearly describes the target user has to be defined and the learning experiences and outcomes must be established [81]. The ease of use of immersive VR systems is critical as well, proving better focus and more mental intensity in users, which results as a consequence, in performances with higher degrees of creativity [82]. Moreover, before designing VR or AR applications for education, a number of issues should be taken into consideration carefully: target audience, level of the course (undergraduate, post-graduate), pre-requirements, topics addressed, learning approach and class format, hardware and software to be used, practical assignments, group organization, staff requirements and main difficulties and constraints related to the use of these technologies [83].

The European Inspiring Science Education (ISE) project provides educational tools and resources linked to e-learning. The European Inspiring Science team sees VR and AR as potentially powerful educational tools to support learning, but only if following the next characteristics are met:

- Intelligent: the classroom technology should adapt and support practices that used to require intense human intervention.
- Interactive: the classroom technology should boost interactions between the instructors and the learners.
- Personalized: the classroom technology should adapt to the needs of individual users.
- Integrated: the classroom technologies should be integrated in a single system. [69], [84]

Both VR and AR technologies present their own advantages depending on the context, situation and the need they are intending to support. When considering whether to use VR and AR or not, one should always take the following questions into account:

- Does the technology allow me to do something that I cannot do without it?
- Does the technology allow me to create the solution easier, in less time, and with the same or greater accuracy?
- Is it feasible to implement the technology?

If the answer to all the previous questions is affirmative, then it is reasonable to implement the technology [85].

2.6. Automation and Robotics

2.6.1. Which Automation/Robotics topics can be combined with a VR/AR application?

Some of the main topics that the MILAN project will cover are: types of industrial robots, industrial robot manipulators, industrial robot operation, robot programming in industry, types of end-effectors, robotics in the automotive industry, robotics in arc welding, robotics in material handling, occupational safety and safety of industrial robotics. In [70], [86], VR is described as a very useful industrial workspace training tool as well as a tool for safety training. In this sense, a VR training tool can provide learners with the fundamental skills to perform a job (understanding the basic function of the job, how to wear the personal protective equipment or how to spot and utilize other tools) as well as to learn critical safety measures before doing any actions at the workplace.

Other approaches suggest a collaborative virtual environment, utilizing a VR Robotics simulator and implementing the communication with a physical robotic system, allowing the simulator to load programs and to even synchronize the simulation with the physical execution of the robotic system [87].These ideas match with the target group specified in item 2.4.1 (people employed at SMEs: workers operating advanced machines as well as middle-level technical staff; teachers, trainers, consultants in the field of Robotics and Automation and students of vocational schools). The positive results with virtual reality in the field of robotics, automation, manufacturing and industrial safety practices obtained in [70], [86], [87] make virtual reality the most optimal technology to use in this work.

2.7. Chapter 2 - Conclusions

The following conclusions (first principles or fundamental truths) are extracted from the analyses of information performed in this chapter:

- Learning is a process that produces change in behavior due to experience which enhances the potential for improved future performance.
- Learning involves change in knowledge, beliefs, behaviors, attitudes and patterns of acting, thinking and/or feeling.
- Learning is a consequence of the individuals' respond to their experiences (conscious, unconscious, past and present).
- Learning is an ongoing process that continues in time for the remainder of individuals' lives.
- Learning can be divided into three main groups: Learning led by survival instinct, goal-driven learning (triggered by desires) and imposed learning.
- Practice and repetition are needed in order to learn new information and keep it in the long-term memory.
- Practice and repetition are needed to strengthen knowledge.
- Theoretical knowledge must be systematically put into practice.
- The emphasis must be on the design of the e-learning course, the learning materials, the explanations, examples and tasks. Essentially, that is analyzing what learners need and providing them with the learning solution in order to maximize the value given to students. Instructors must serve learners.
- Learning styles should be considered for each independent learner, prioritizing first kinesthetic, and then visual, auditory and read/write learning styles.
- Hands on work, projects, real experience and practice must be emphasized.
- Activities designed to support learning should be a blend of visual, auditory, read-write and kinesthetic modalities.
- Positive reinforcement stimulus should be utilized to motivate students.
- Motivation must be always enhanced by showing learners their goals, their objectives, their progress, and giving them rewards.
- New information should be kept in the long-term memory, which stores and retains data for long periods of time, that go from months to an entire lifetime.
- To maintain information in the long-term memory, information stored in short-term memory should be repeated over time.
- Memory combined with association helps to improve the access to long-term memory.
- Spaced repetition minimizes the forgetting effects and helps individuals remember for longer periods of time.

- Feedback should be always given to students to control and direct their progress.
- Media content must be utilized, such as pictures, animation, video lectures, 3D models, simulations, e-textbooks, etc.
- Forums or other spaces open to questions and discussions must be available.
- Students must always have a clear picture of the objectives and steps to be completed to reach their goal(s)
- The students' performance must be measured through time in order to control (and redirect if necessary) their progress.
- Learners should not have geographical or time constraints for learning.
- If previous knowledge is not built upon strong foundations, it can hinder the individuals' learning progress. It is better to give the learner a path to begin from scratch if it is not evident that the learners' knowledge foundations are solid.
- Social aspects, interaction with the instructor and collaboration with peer students enhances engagement, motivation and therefore boosts learning.
- Success rate is higher among students in e-courses that are led by an instructor than e-courses with independent-study styles.
- Opportunities to cheat of e-learning students can be minimized by adding an in-campus supervised environment to take the exams.
- Course requirements information must be given to students as well as options to acquire those pre-requirements.
- Course information must include: "What you will learn", "Who this course is for" and "What the course includes" (resource types, practice tests, access type and certification, language of instruction and subtitle options).
- Including a certification of completion is a motivator for learners to finish the course.
- Customer average rating and number of ratings for each course must be available to learners to verify the quality of the program or course.
- Big discount deals for limited periods of time prompt the users to enroll quicker.
- Showing the featured reviews and their achievements motivate students to enroll faster.
- Preview of the course contents must be available for students. Giving a taste of the full content lead to more and faster enrolments.
- Risk-free strategies, such as a 30-Day Money Back Guarantee result in higher number of enrolments.
- Information about the instructor, his or her qualifications as well as his or her ratings and reviews from students must be available.

- Showing individuals a quick view of the path they will follow (beginner, intermediate and/or advanced level) helps them to visualize where they start and where they get at the end of the course and increases engagement.
- Estimation of the number of hours needed to complete the course must be available to students (i.e. months and hours per week).
- 10 days free trial to use the platform or course increases user enrolment.
- Frequently asked questions section for each course increases user engagement and can lead to faster enrolments.
- Perceptions in the sense of accomplishment (learners notice the progress at each moment in time and perceive new gained skills), mastery of skills (learners feel very confident and capable to put the new knowledge into practice), perceived utility of learning (learners understand how that knowledge can be useful to them), meeting career goals (individuals clearly see how the learned information will help them meet their specific goals) and ease of use, all enhance academic achievement drastically.
- A critical factor influencing student persistence is dependent on the number of hours of virtual learning environment usage.
- Regular study has been described as the strongest predictor of academic achievement. Creating study habits is key.
- A feeling of connection with the entity delivering the course increases time spent in the learning system.
- Guidance at the beginning of a program or course (such as SSC) on how to develop essential time management and study skills as well as career planning assistance enhance student engagement, persistence, retention and academic achievement.
- Habits are immediate automatic response triggered by emotions (more generally more linked to negative emotions).
- To form habits, frequency and perceived utility should be boosted. The more frequency and perceived utility, the stronger the habit.
- The four phases of the Hook Model: Trigger, Action, Investment and Variable Reward must be applied to create effective habits.
- Trigger is the first phase of the model. Triggers can be internal and external.
- In order to create habits, products must start showing users external triggers such as e-mails, an app icon, SMS or a phone notification.
- After several cycles using external triggers, individuals are prompted by internal triggers. These are emotions (being negative emotions such as stress, frustration, loneliness or confusion the most powerful ones). These emotions must be mitigated by the solution designed for the users in order to create habits.

- Action is the second phase of the Hook Model. In this phase, users take action.
- For action to happen, individuals must have the ability and motivation to do something.
- Right motivators create action by promising an outcome that the user desires.
- Every behavior is driven by one of the three core motivators: searching for pleasure and escaping from pain, searching for hope and escaping from fear and searching for social acceptance and escaping from social judgement and rejection.
- Ability refers to how easy it is for users to perform the action. The easier (simpler), the better.
- Simplicity to boost ability depends on six elements: time (how long it takes to perform the action), money (how much it costs), physical effort (physical activity required to take the action), brain cycles (the mental effort needed to complete the action), social acceptance (level of acceptance of the action by others), non-routine (degree of disruption of the action with current routines).
- Variable reward is the third phase of the Hook Model. Motivation is enhanced when individuals are aware that they will receive a reward after completing an action.
- Rewards of the tribe (seeking for social rewards powered by connectedness with other individuals), rewards of the hunt (seeking for resources and information) and rewards of the self (seeking for rewards of competence, completion and mastery) can be utilized to boost motivation.
- Variable rewards maintain users' interest over time by adding variability.
- Investment, the fourth phase of the model involves commitment from the users' side. Individuals that invest more time and effort into a product, value it more and engage more with it.
- VR and AR applications can enhance adoption of course materials.
- AR allows users to interact with the physical world, something that it is not possible with VR.
- VR is more effective for immersive user experiences.
- VR is more effective communicating visual content.
- VR environments are a powerful tool to provide on-site training.
- VR is effective enhancing learners' understanding of abstract concepts.
- AR helps to attract and maintain students' attention and enhances their concentration towards practical tasks.
- AR has also been proven effective helping learners understand abstract concepts.
- AR allows to free educators from determining the learning contexts and situations, as the conditions of the physical world specify all of them.

- Before designing a VR or AR environment, learning objectives must be clear and the target audience and their social and academic characteristics must be analyzed.

- VR or AR applications should be designed to improve interactions between instructors and learners.

- VR and AR applications should be integrated into a single system together with the e-learning environment to increase the ease of use.

- The access of the virtual reality or augmented reality app must be provided to students at anytime, anywhere and without the need to purchase expensive equipment.

- Previous studies have shown that virtual reality is the most optimal technology to utilize in the fields of robotics, automation, manufacturing, and industrial safety practices.

- In order to design a VR or AR environment for education, an affirmative answer must be given to the following three questions: (1) Does the technology allow me to do something that I cannot do without it? (2) Does the technology allow me to create the solution easier, in less time, and with the same or greater accuracy? (3) Is it feasible to implement the technology?

3. E-LEARNING ENVIRONMENT DESIGN

3.1. Combining E-learning with Virtual Reality

After the literature review and the analysis of information, this work will focus on generating an effective synergy between e-learning environments and virtual reality. As explained in item 2.6.1, the positive results with virtual reality in the fields of robotics, automation, manufacturing and industrial safety practices obtained in previous studies [70], [86], [87], make virtual reality the most optimal technology to use in this work. In the following sections, the e-learning environment design will be described. All the figures contained in this chapter are available in Appendix 1 with larger dimensions for a better visualization. Section 3.10 explains how virtual reality can be included and utilized in the e-learning environment.

3.2. Goal-Driven Strategy

Figure 3.1 shows the e-learning environment design created according to the first principles presented in section 2.7. It is important to note that the environment has not been developed or programmed. It has only been graphically designed to visually explain the key elements to be included for an effective habit-forming learning experience combined with virtual reality.
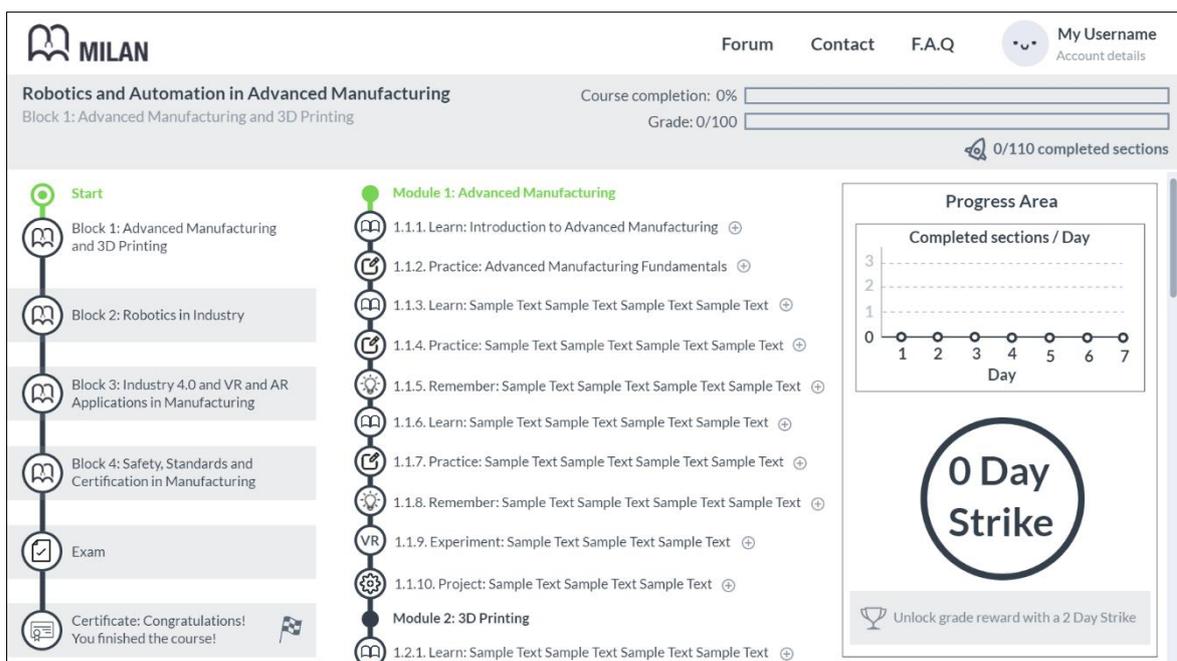
Figure 3.1. Study area of the E-learning environment design

With this design, learners can clearly see the beginning and end of the course. It is always clear where they currently are and how far they are from the end course. This is achieved with the map-like view of the course and the progress bars in the upper right corner. In addition, students can graphically see how many steps they need to go through before reaching their end goal, both in the left side general view (blocks, exam and certificate) and in the central map view (sections to be completed per module and block).

Being a self-paced online course, the learner has the encouragement to finish the course, take the exam and obtain a certificate at the end (one of the rewards given to the user). The certificate acts like a reward and the grade is used to maintain the motivation through the whole course.

3.3. Triggering the learner

The environment is designed to calm down the "itch" from many negative emotions that learners may face, such as the feeling of not being constant enough, of not making substantial progress towards goals; the fear of not being smart enough; the need for social approval and acceptance by mates, friends and family; the lack of self-esteem due to limited knowledge on a specific subject; and the positive emotion of hope/desire for a better and more promising future (reaching life goals). All these emotions can be utilized as internal triggers, just as described in The Hook Model [63]. The environment has been designed to psychologically relieve the pain caused by those negative emotions, thus incrementing the number of needs solved to the user. Throughout the e-course, the learners would be prompted with an external trigger (i.e. an e-mail) every day, that would remind them to complete a section of the course. After several repetitions, the habit would start to form. Every time there is psychological pain relief from those negative emotions, the user gets more hooked to the e-environment.

3.4. Taking action

In order to take action, the learner must have sufficient motivation, the ability to complete the desired action, and a trigger must be present to activate the behavior. The trigger part has been covered in section 3.3. Motivation is boosted by linking it to the external triggers received every day (reminders to prompt the user into entering to

the e-course). With the constant graphical visualization of achieved progress and with the variable rewards systematically received, the learner completes a section or reaches a 2-day usage strike (later described in more detail). The ability part refers to the ease of use. The design has been created to eliminate as many unnecessary steps as possible, reducing the time to complete the desired action, and the physical and mental effort (brain cycles) of labor involved in taking an action. It also enhances the feeling of social approval as well as the social interaction (certification at the end, comment sections and forum).

Once the user clicks on the first section of the e-course (marked as '1.1.1 Learn' in Figure 3.1), the task opens, and the user begins the learning journey. Figure 3.2 shows a graphical visualization of it when it is open. Section 1.1.1 of the course is of the type 'Learn'. This type of sections intends to provide more theoretical explanations to the learner. In order to provide the best learning experience to users with different learning styles, the materials must be given in video format as well as in written format, such as PDF.
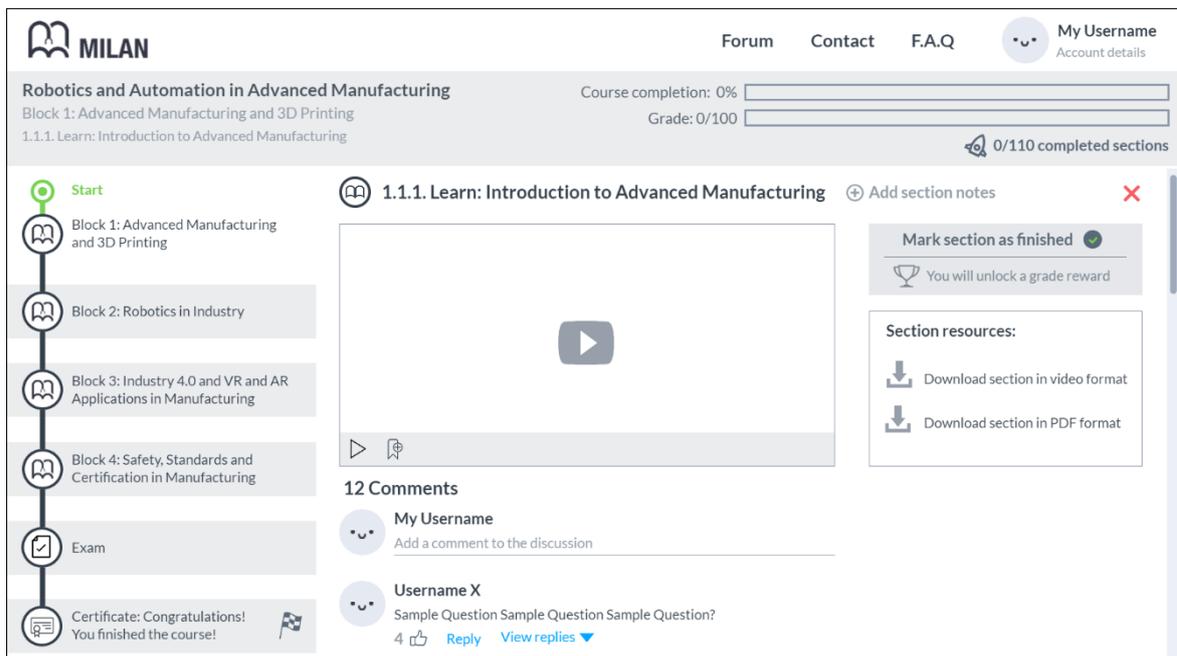
Figure 3.2. Section 1.1.1 of the e-course, of the type 'Learn'

It is critical that lectures are given in video format, allowing learners to pause and play the video as many times as needed. Next to the 'Play' button, the video also contains an option to generate bookmarks (notes/comments) and place them throughout the video length. These bookmarks can be utilized by the student to mark the most important moments of each explanation. It is important to note that under each video lecture, there is a comment section area, where the users can ask questions related to

the section. This enables students to interact like in a real class, but it also increases the student-teacher as well as the student-student interaction. As illustrated, the users can vote positively every question or comment (enhancing the internal trigger related to the need for social approval and acceptance), reply or view other replies. All these options are included to enhance the social interaction and develop in the learner the feeling of community and being part of a group (proven critical to increase motivation).

On the right side, there is an area available to download the materials both in pdf and video format. Moreover, next to the title of the section, there is an option for the student to include comments/notes to that specific section. For every comment/note and bookmark added, the user invests time and effort into the platform, which is a critical step in the Hook Model in order to develop habits [63], as previously explained in chapter 2.

Finally, on the right side, there is an 'X' icon to close the section if it has not been finished yet. Under it, there is a button to be used when the learner has completed the section. This is a key element of the e-environment. The button says 'Mark section as finished. You will unlock a grade reward'. This is the first time that the user will be given a variable reward. The user does not know what will be given when the button is pushed. That is exactly what will begin to get the learner engaged and hooked into the system. The next section gives a more detailed description of the variable reward system.

3.5. Variable rewards as small bites of the final grade

Students care about the grade, because it is generally what defines whether they pass a course or not. It is also a way to show their level of expertise on the subject, which is strongly linked to every human's need for social approval and acceptance. That is why, giving learners the grade as variable rewards in small bites is a powerful way to keep them engaged. It also shows learners the importance of constant and persistent work in order to reach a final goal. Figure 3.3 shows what the user sees once the button to receive a variable reward is pushed.

This type of reinforcement has been discussed in chapter 2, and it is an effective way to make the user associate the desired action with the reward in order to do it more often. The message also includes the phrase "Well done!", which is psychologically relieving pain from some of the negative emotions discussed in section 3.3 of the thesis: not making any substantial progress towards a goal; the fear of not being smart enough;

the need for social approval and acceptance; and the lack of self-esteem due to limited knowledge on a specific subject. Then, it can also be observed that the first section turns green (marked as completed), constantly emphasizing the investment that the learner has already done in the system. This element also shows the achieved progress, but there are several other elements doing so. Once the first section is completed, the progress bars are updated ("Course completion: 0.9%" and "Grade: 0.25/100") and under them, it is indicated that there are already "1/110 completed sections" (the total number of sections was invented for the purpose of illustration).
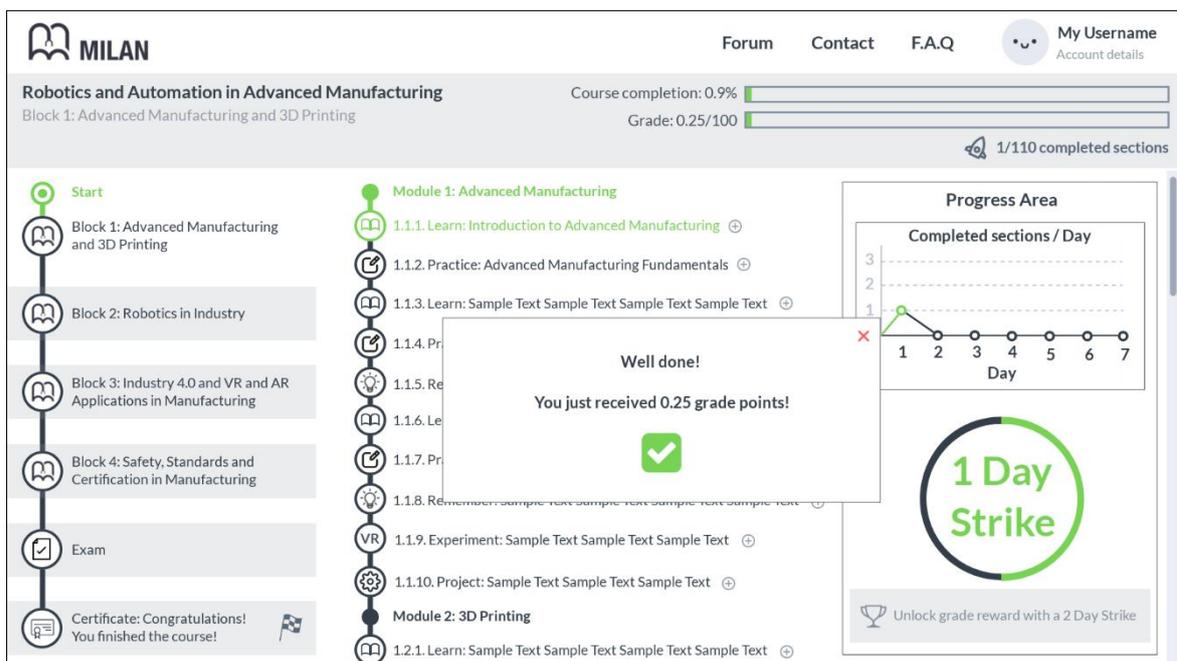

Figure 3.3. Applying positive reinforcement - User receiving a variable reward

On the right side of Figure 3.3, the progress area has been updated. This area is always displayed to the learner. After completing section 1.1.1 of the course, it is showing a chart that includes a green dot specifying that one section was completed in the first day. The idea is that, after several days, the chart will be full of green dots and the user will not want to "lose" the satisfaction of seeing that chart always green. Under it, the progress circle is reporting that the user has achieved a one-day strike. Under it, there is a button to unlock another grade reward. It can be unlocked with a 2-day strike. So, in order to get another small bite of the grade, the learner must come back the next day to the system and complete at least one section more. These are bonus or extra points, representing only a total of 5 points out of the 100. Thus, if the user returned to the e-platform every day and did all the sections and exams correctly and systematically, a total punctuation of 105 could be reached. This model not only gives

an extra portion of the grade by making the user return to the site, but it also works in parallel with the other elements to hook the user into learning.

3.6. Practice makes perfect

If the learner clicked on section 1.1.2, a new section would open of the type "Practice". In Figure 3.4, this type of section is shown. It can be observed that an exercise is proposed to the student. Depending on the type of course or the materials previously studied, other practical tasks could be proposed (i.e. a quiz). Under it, the student can provide the answer to the different questions. After that, the student can click over "Check Answers". In the same button, it is specified that, if the answers are correct, the section is marked as finished and the learner unlocks a grade reward. In case that the student does not know how to solve the exercise, an option to watch the solution in video format is provided to the user. Under the video, a comment section would be again available for possible questions that may arise. On the right side, a resources section contains the options to download the problem statement in PDF format, and the solution in both PDF and video format.
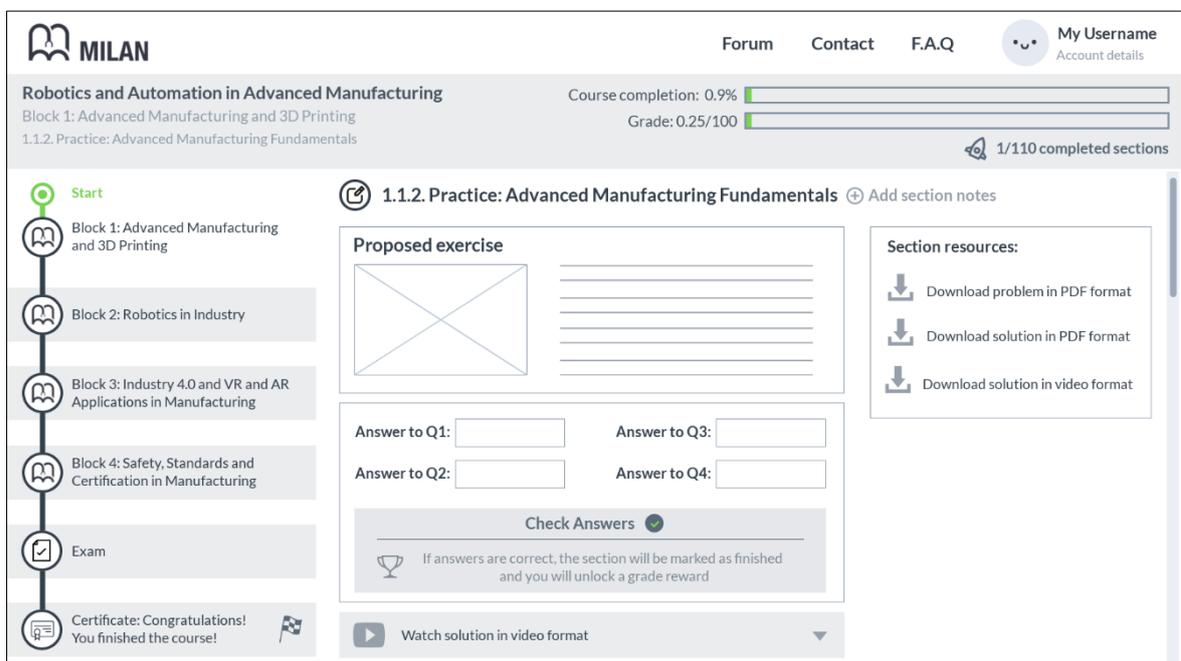
Figure 3.4. Section 1.1.2 of the e-course, of the type 'Practice'

These practical sections must be included throughout all the modules of the e-course, since systematic practice is key to develop an adequate and solid base of knowledge, as described in chapter 2. Figure 3.5 shows the interface after completing section 1.1.2.
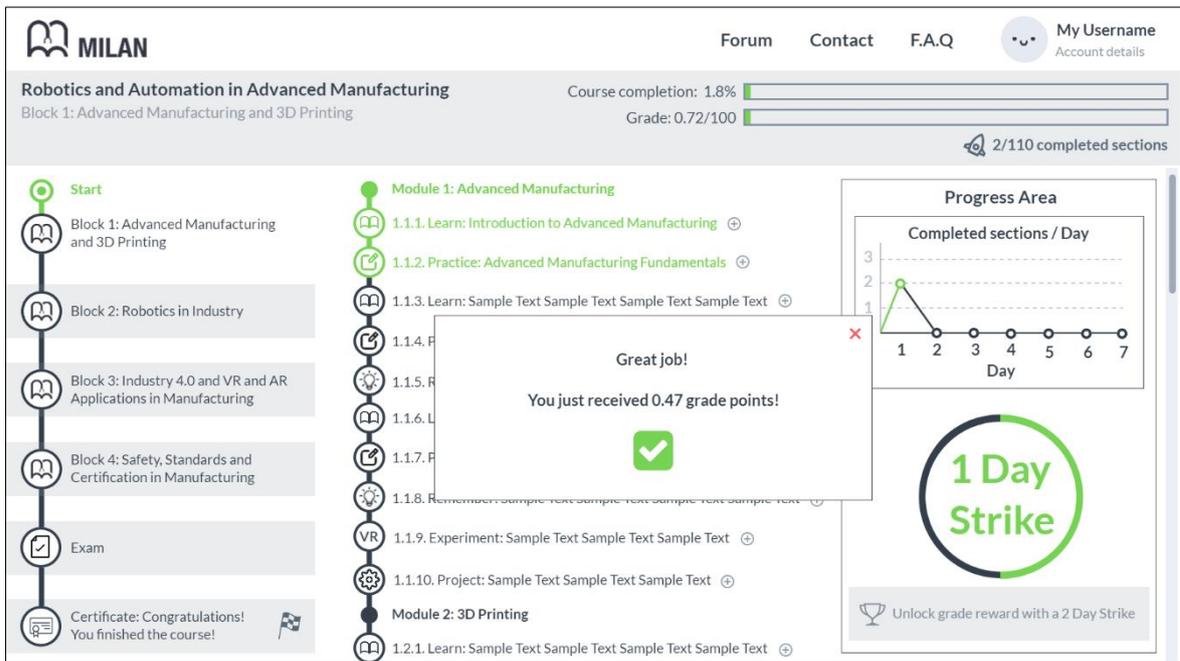
Figure 3.5. User receiving a variable reward after a practical section

In Figure 3.5, a new variable reward would be given to the user, receiving in this case a larger amount of grade points than in the learn section. Here, it is important to note the key element of variability in order to create a stronger psychological connection between the user and the e-environment, just as described in the experiments undertaken by B. F. Skinner [67]. The completed sections per day in the progress area (right side) are updated to two sections completed on the first day. The progress indicators are again increased to show the current progress.

3.7. Investment by the learner

As shown in Figure 3.6, on the second day, after completing section 1.1.3 of the e-course (type "Learn"), the student unlocks a grade reward for completing a new section of the course. The progress counters in the upper right zone are then updated.
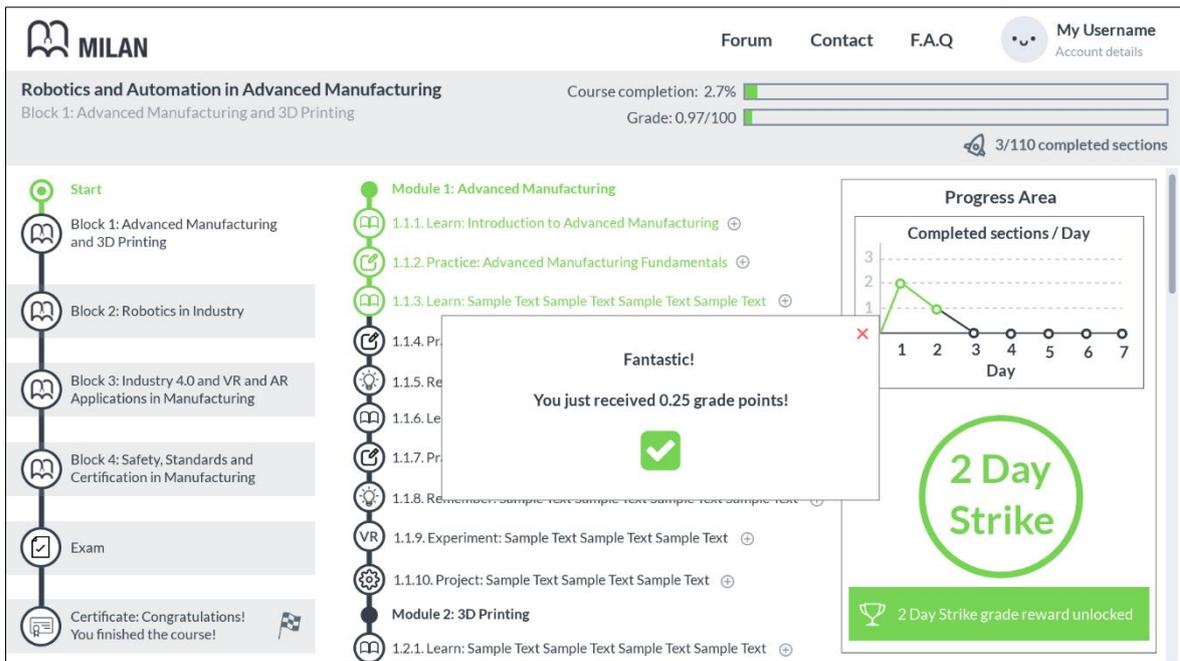
Figure 3.6. 2-Day Strike grade reward being unlocked

In the progress area, the second day of the chart shows that a section has been completed. Under it, the second day strike grade reward appears as unlocked. After closing the current message displayed on the screen, a new pop-up message indicates that the user has earned certain amount of points due to continuous work (Figure 3.7).
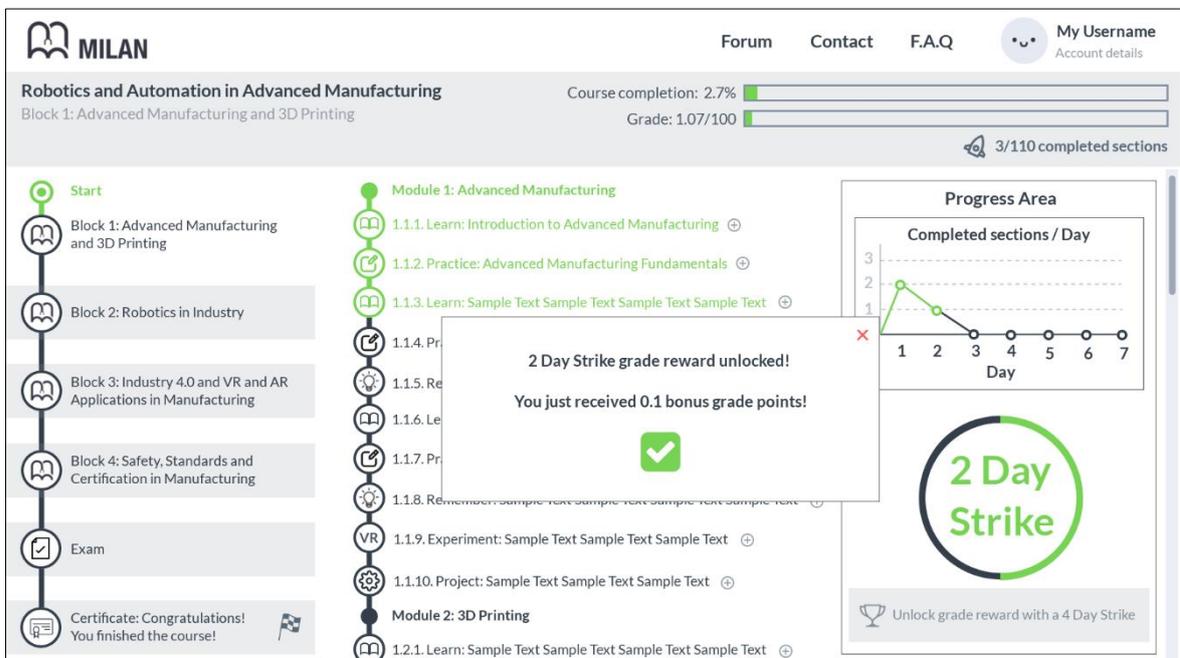

Figure 3.7. Receiving 2-Day Strike grade reward

The user then unlocks 0.1 points of the bonus points assigned as rewards for continuous work. The counter displays that the next grade reward can be unlocked with a 4-day strike. It is noteworthy that, as the number of completed sections grows and more section notes and bookmarks are added, the investment done by the learner in the platform increases as well. Since the investments in a product create preferences towards that specific product due to the human tendency to overvalue our own work [63], the likelihood of learners returning to utilize the e-platform is higher.

3.8. Spaced repetition

In Figure 3.1, some of the tasks are marked as "Remember" (1.1.5 for example). When a practical task has been completed, the material is learned by the user. However, after some time, the Ebbinghaus' curve shows that the knowledge begins to be forgotten [39]. In order to avoid this effect, the solution is to place certain remembering tasks after some time. As presented in Figure 3.8, the remembering section looks just as a practical section, allowing the users to practice again some previous sections of the type "Practice" completed in the past.

Figure 3.8. Applying spaced repetition - Section of the type "Remember"

3.9. Forum

In Figure 3.9, several icons are placed in the upper right corner. One is for the profile details and the username, and the other three next to it are meant to address issues that students may have.
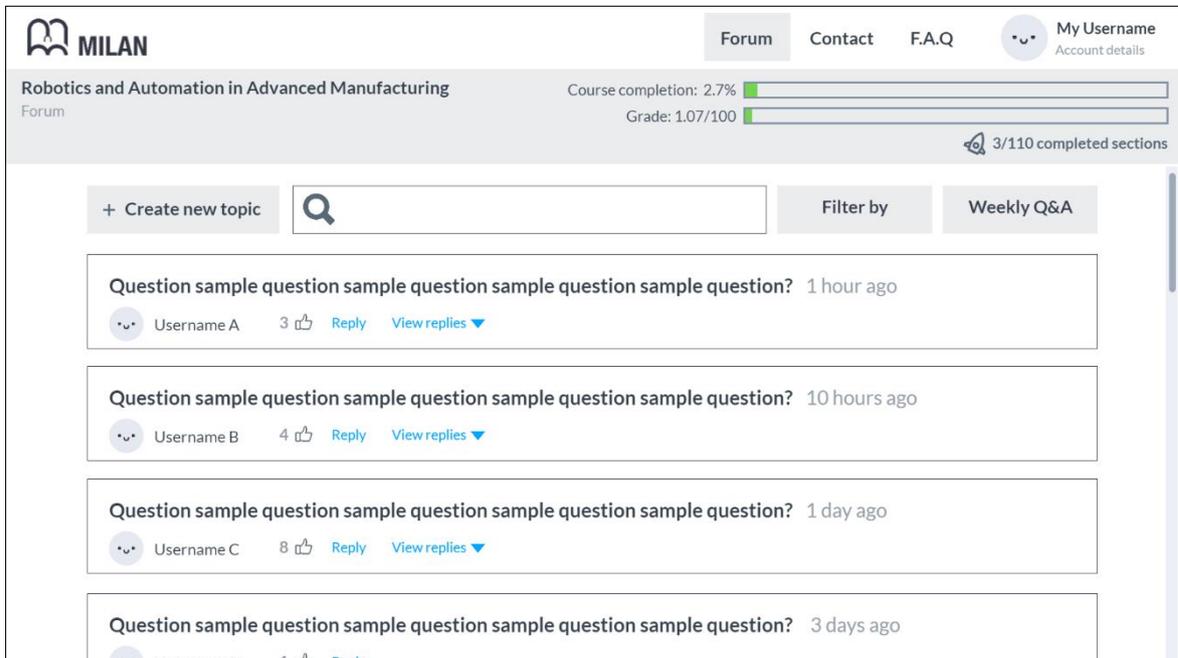
Figure 3.9. Forum area of the e-course

The button for "F.A.Q" is an area with frequently asked questions that the students may have had previously while using the platform. In addition, a user guide could be provided in this area. The area for "Contact" provides contact details. The area "Forum" would be utilized by students and instructors to post information or questions about certain topics that must be addressed during the development of the e-course. In there, users can interact with each other and with the instructors, enhancing the social interaction needed to boost motivation. Moreover, it increases the investments made by students in the e-environment. There would also be a button named "Weekly Q&A", where live streaming videos with student questions could be uploaded weekly. The Q&A would enable learners to ask questions on live directly to the instructors as well as interact with them.

3.10. Virtual Reality tasks

In Figure 3.1, there are some other types of tasks, such as "Experiment" and "Project". These tasks may be less common than the previous ones, depending on the type of course.

In the sections of the type "Project", the instructions to develop a certain project could be given to the learners, if all the necessary knowledge has been previously delivered to the learners through the "Learn", "Practice" and "Repetition" sections.

The "Experiment" sections point learners to download the VR app on their phone and complete a specific level that will support learning. The VR application is one more of the sections that students could utilize in order to acquire knowledge. In the e-course, virtual reality must be used as tool to achieve the objectives of a course. It must help to deliver the contents and enhance the learning experience. If the virtual reality technology enables the instructor to do something that cannot be done without it, then the "Experiment" section for virtual reality must be included. Otherwise, other ways that may be more feasible to implement shall be studied. The virtual reality tasks provide learners with a larger amount of practice to learn certain topics that may need of a more immersive or interactive experience.

3.11. Gamification of education

Many of these elements are also present in many popular and viral games: the map-like view from beginning to end, the goal-driven strategy, the utilization of variable rewards and other elements to treat the user, the use of designs that hook the user by displaying all the investment already performed, the creation of habits by the utilization of internal and external triggers, etc. This is how users get hooked into games. The idea behind the design of this e-environment is to hook users as well, but into learning instead. The utilization of these elements is justified if it means a larger number of learners engaging with learning and developing strong study habits in their routines. Previous studies have shown that using gamification for learning purposes increases student engagement, grades [88] and has a positive impact on learning outcomes [89].

4. VIRTUAL REALITY APPLICATION FOR LEARNING

4.1. Virtual Reality App Design

In this section, the design of the virtual reality application is described. The graphical user interface as well as the interaction between the user and the application is explained.

4.1.1. Virtual Reality app usage with the e-learning environment

As explained in section 3.10, the virtual reality tasks of the e-environment will point the user to download an app to their mobile phone and complete the specified level or task in order to support the adoption of materials. The reason for this is that, as described in item 2.4.1, the MILAN project e-course is prepared for the delivery of content online. Therefore, learners need the virtual reality environments to be accessible anytime, anywhere and without the need to purchase expensive equipment.

These requirements suggest that the most efficient manner to provide learners with virtual reality technology is by using their own smartphones or tablets, just as suggested in previous studies [3], [7]. The utilization of these devices enables learners to immerse themselves inside virtual worlds with practically no cost. Only a VR headset is necessary, which can be found on the internet for prices under US $3 (i.e. Google Cardboard headsets). Thus, in this work, the virtual reality environment has been designed for mobile devices in order to cover the needs of the user. It is important to note that, although it has clear benefits by reducing the cost for the user to almost zero and reaching every student with this design, the interactive experience is somehow lowered. As explained in the next items, the designed virtual reality is immersive and interactive, but the learner has no controllers. Thus, everything has been designed taking into consideration that the learner may not own the professional virtual reality controllers or headsets currently available in the market. Everything can be selected and controlled only by pointing to the game objects with the head. This is done with the use of a reticle pointer, which is explained further in the following items and sections.

Nonetheless, it is noteworthy that in the VR tasks of the e-learning environment, the learner could be informed that the virtual reality app is also available for professional VR headsets, such as Oculus Rift or HTC Vive. With a few modifications, the app could be exported to work with these devices.

4.1.2. Software

The design and development of the VR app has been done in the Unity game engine (version 2019.3.7f1). Unity is a development platform that allows to create 2D, 3D, virtual reality environments and then export them for different platforms (Android, iOS, Oculus Rift, HTC Vive, etc). In addition, the integrated development environment Microsoft Visual Studio 2017 has been used to develop the correct functionality of the app in combination with the C# programming language.

4.1.3. VR Main Menu

Figure 4.1 shows the main menu of the virtual reality app. The menu is the first screen that appears when the user opens the app. It is displayed with a fading effect from a completely dark screen to the main menu with default brightness. This is utilized not to generate brightness discomfort when the user first opens the app.

Figure 4.1. Main Menu of the virtual reality application

The background includes a representative picture of an automotive manufacturing environment, directly related to the materials of the e-course. In the upper part, the title shows the message "Welcome to the MILAN VR environment". The title is not an interactable element. Under it, there are three more buttons. All of them are interactable. When the first button is selected, it will load the first virtual reality task.

The second button loads the second virtual reality task and the third button labelled as "EXIT" will quit the app when selected.

If any of the buttons is chosen, a reticle timer with a radial 360-degree filling effect is used to show the user that this button is about to be selected. This reticle timer is displayed for 2 seconds to allow the user to change the option if desired. When the 360-degree filling effect is completed, the button turns green and a fading transition begins (Figure 4.2). After that, the selected virtual reality task opens.

(a)   (b)

Figure 4.2. Reticle timer with a radial 360 degrees filling effect (a) and button selection (b)

The Main Menu also includes a background music that will play until a task is selected.

4.1.4. VR Task 1 – Animation

The first virtual reality task deals with the understanding of robot axes and their importance in generating motion. When the user selects the task, an animation is displayed to the user on the first place.

The animation shows a 360-degree view of an industrial robot, and then it proceeds to describe what the axes of a standard six axis industrial robot are and how they work. The animation generated in unity itself, combines a tridimensional visualization of the robot in motion and other bidimensional elements such as signs and arrows that identify each axis while the animation and audio is playing (Figure 4.3).

(a)   (b)   (c)
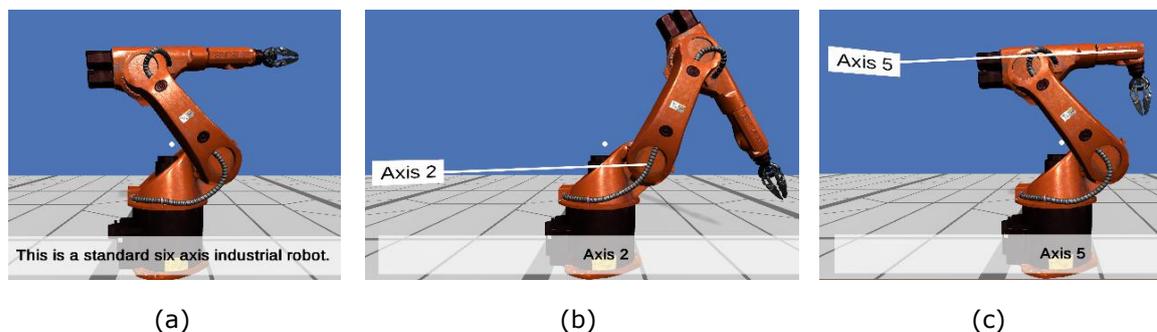
Figure 4.3. 360-degree view and explanation of industrial robot (a), robot rotation on axis two (b) and robot rotation on axis five (c)

This was utilized to enhance the understanding of the user about what a standard industrial robot is, how many axes it has and how they work. After the animation, the immersive and interactive task begins. In order to generate the audios with the necessary explanations, the text to speech online demo tool by IBM was used [90]. The robot model was obtained from the Unity Asset Store [91].

4.1.5. VR Task 1 – Immersive and interactive environment

Figure 4.4 (a) shows the user's view of the interactive environment for the first virtual reality task. In the upper part the instructions are constantly displayed to the user, which are also played as an audio at the beginning of the task. The audio also indicates that the laser attached to the robot end-effector will help the user understand where the robot is pointing to. The point of the task is to move the robot in order to pick the red item and place it on the conveyor belt. Learners can practice and have a better understanding about how the robot rotation on different axes allows to reach diverse points on a three-dimensional space, as well as performing other activities such as the "pick and place" types of tasks.

In the left area of the environment, the buttons show the options that the learner can choose from. It is possible to select one of the axes or the robot tool (in this case a gripper) to generate motion. When a button is selected, as shown in Figure 4.4 (b), the button turns green to let the user know that the selection was completed. By pointing and hovering over the slider, the learner can generate motion and rotate the robot on that specific axis. Figure 4.4 (b) reveals how several combinations of rotations on different axes help the user to reach a desired position.

(a)   (b)
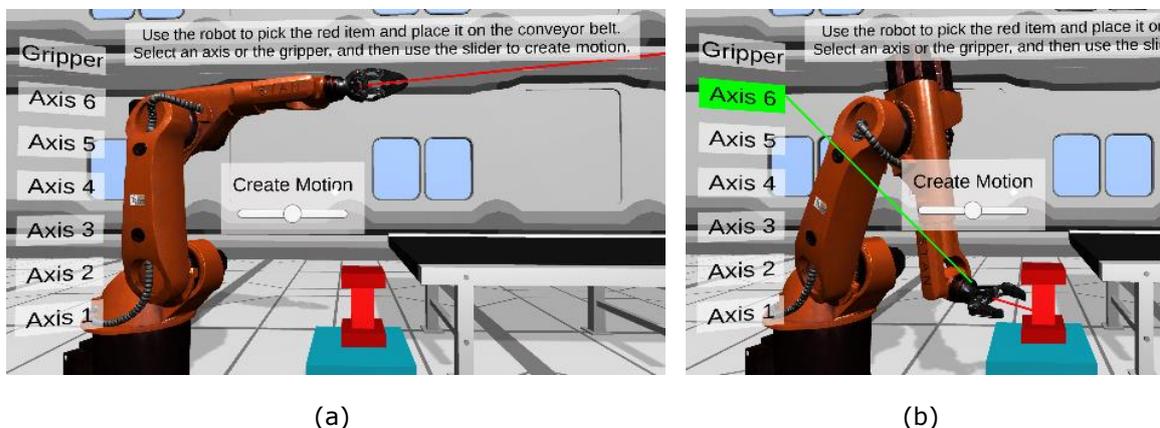
Figure 4.4. VR Task 1 initial view (a) and positioning of the robot by using the axis selection buttons and the slider for motion generation (b)

(a)   (b)
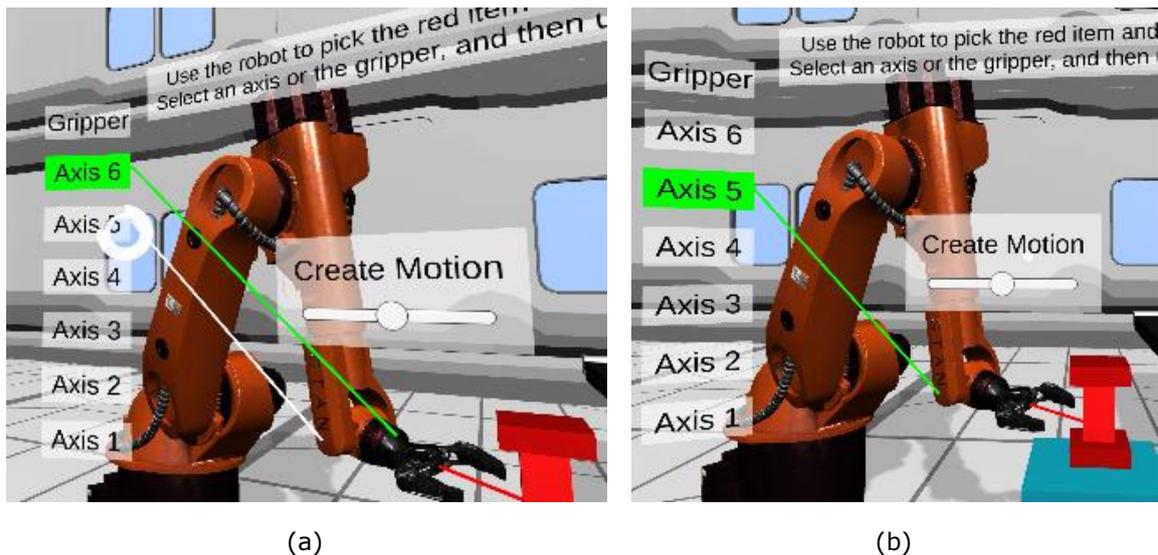
Figure 4.5. User choosing a new axis (a) and completed change of axis selection (b)

In Figure 4.5 (a), the selection of a new button is shown. When the learner hovers over a new button, a white line indicates what axis is about to be selected. The reticle timer with a radial 360-degree filling effect appears. When the whole circumference is completed, the new button is selected and the previous one is unselected, as displayed in Figure 4.5 (b).

When the task is completed successfully, a message is displayed to the user, as shown in Figure 4.6 (a). Figure 4.6 (b) presents how once the user picks the item and places it on the conveyor belt, the object is slowly transported to the next area of the manufacturing facility through the belt.

(a)   (b)
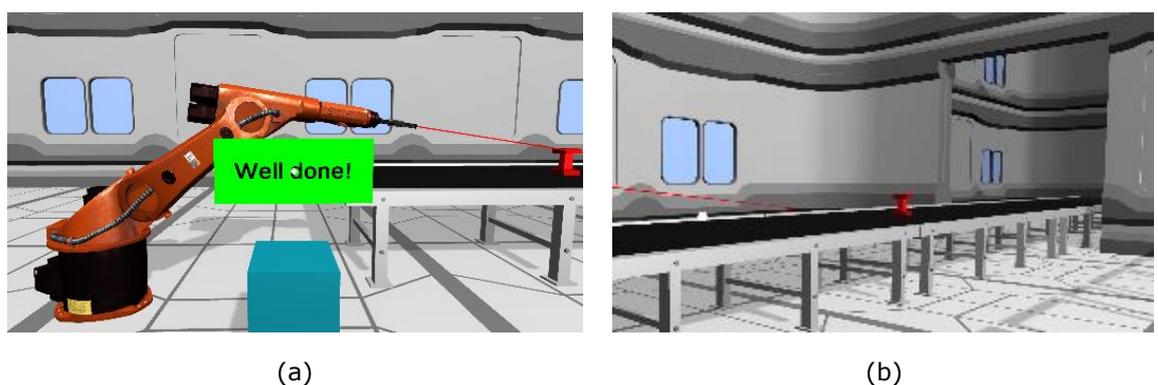
Figure 4.6. Success message displayed when task is completed (a) and transportation of the object to the next area (b)

When the level is completed, a menu pops up giving three options to the user, as displayed in Figure 4.7 (a). The user can then choose to play again the same level, go back to the main menu or quit the app. In addition to this, the user always has the

option to return to the main menu or exit the app. For that, the user must look down (to the floor). When this action is performed, a menu fades in and gives both options to the user. The design of this menu was done is such manner to avoid the inclusion of too many elements in the user's field of view. This menu is available in all the virtual reality tasks designed (including the previous animation).

| (a) | (b) |
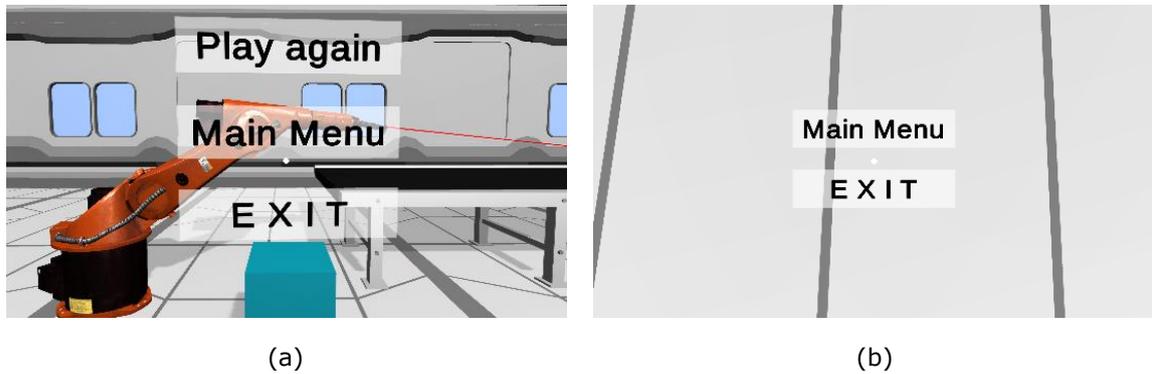
Figure 4.7. End-level menu (a) and look-down menu (b)

To create the walls, the floor and other details of the scene, an asset bundle of industrial models was imported from the Unity Asset Store [92]. Other objects such as tables or the conveyor belt were directly created inside the Unity Engine by the author of this work. The whole layout of this manufacturing facility and other scenes was designed as well by the author in its totality. Figure 4.8 shows more details that the learner can observe when looking around with the virtual reality headset.
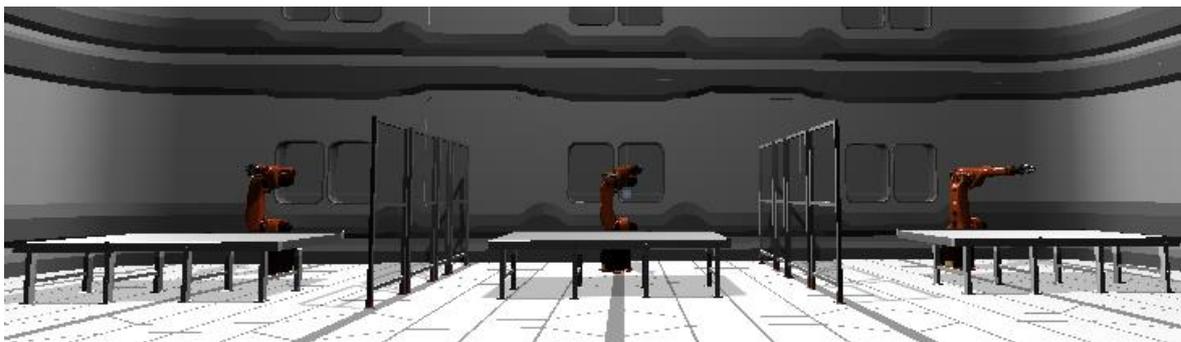
Figure 4.8. Detail of the manufacturing facility layout

4.1.6. VR Task 2 - Immersive and interactive environment

The VR Task 2 is designed to enable learners pick an end-effector required for a specific industrial task. The user can choose from several tools available, grab one, drag it to the industrial robot and attach it.

Figure 4.9 (a) shows the initial screen when the user starts the VR Task 2. In the lower part of the screen, the instructions are given. An audio of the instructions is also played at the start. In this level, a tool must be selected for lifting the car. The learner can hover over one of the tools displayed on the left part of the screen. After that, the radial 360-degree filling effect shows the user that the selection process has started, as presented in Figure 4.9 (b).

(a)   (b)
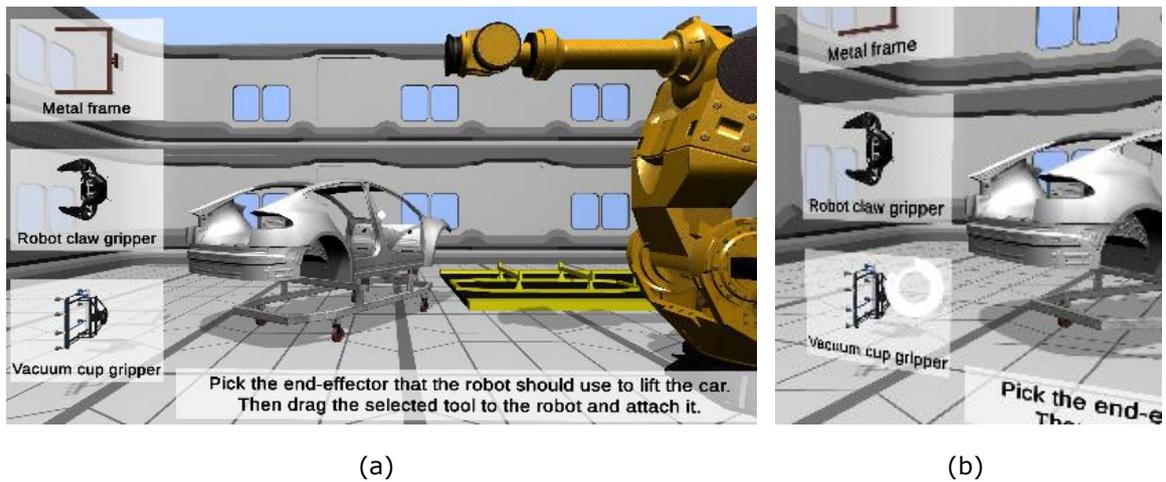
Figure 4.9. VR Task 2 initial screen (a) and tool selection process (b)

Once the end-effector is picked, the tool size enlarges to visually indicate that it is currently selected. It also helps to better visualize the effect of grabbing the object. The user must then drag the tool to the robot in order to attach it. When both objects are in contact, a message informs the user that the end-effector is being docked to the robot, as displayed in Figure 4.10 (a). If the selection is not correct, the learner receives a message informing that the tool was not correct for the specified application and indicates him or her to select an end-effector again, as shown in Figure 4.10 (b).

(a)   (b)

Figure 4.10. Tool being attached to the industrial robot (a) and message informing the user that a new tool must be selected (b)

In addition, if the user wished to unselect a tool, the tool must be placed in its original location. A message will be then displayed in front of the user, with the information that the tool is being unselected, as exposed in Figure 4.11 (a). It is also possible to unselect a tool by directly hovering over another tool. By the end of the radial 360-degree filling effect, the new tool will be selected and the previous one automatically placed in its original location. When the correct tool is selected and attached to the robot, the end-effector turns green and a message pops up letting the learner know that the selection was correct, as presented in Figure 4.11 (b).

(a)   (b)
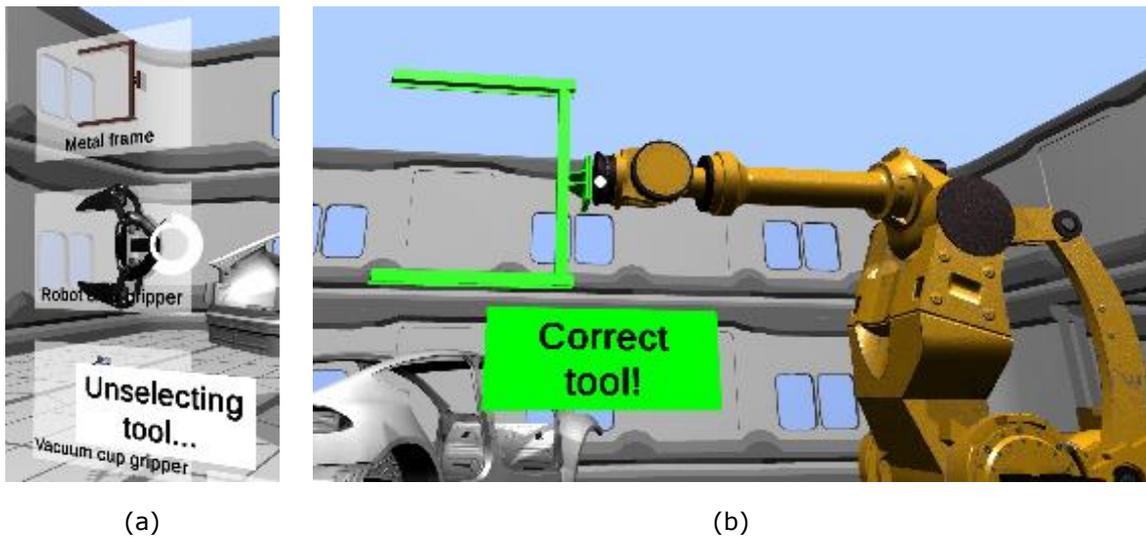
Figure 4.11. Tool unselecting process (a) and message informing the user that the selected tool is correct for the specified application(b)

(a)   (b)

(c)   (d)
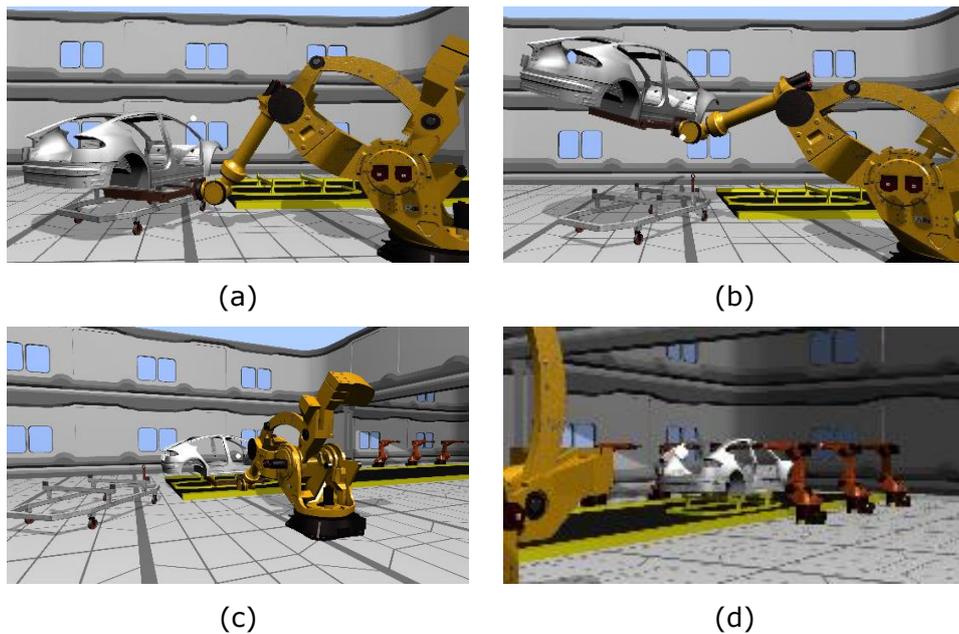
Figure 4.12. Different frames of the animation that shows how the tool is used to lift the car (a), (b), (c) and (d)

As displayed in Figure 4.12, after the right tool is attached to the robot, an animation is played with a voice explanation. The voice explanation transcript is detailed below:

"As you can see, by programming the robots and using different end-effectors, manufacturing facilities have the flexibility to use robots for different purposes over time. In this case, the car is placed over a platform which will take it to the next area to continue the manufacturing process."

At the end of the level, the menu presented in Figure 4.13 (a) is displayed to the user. If the user looks down to the floor at any moment during the VR Task 2, the menu shown in Figure 4.13 (b) will fade in for the user.

| (a) | (b) |
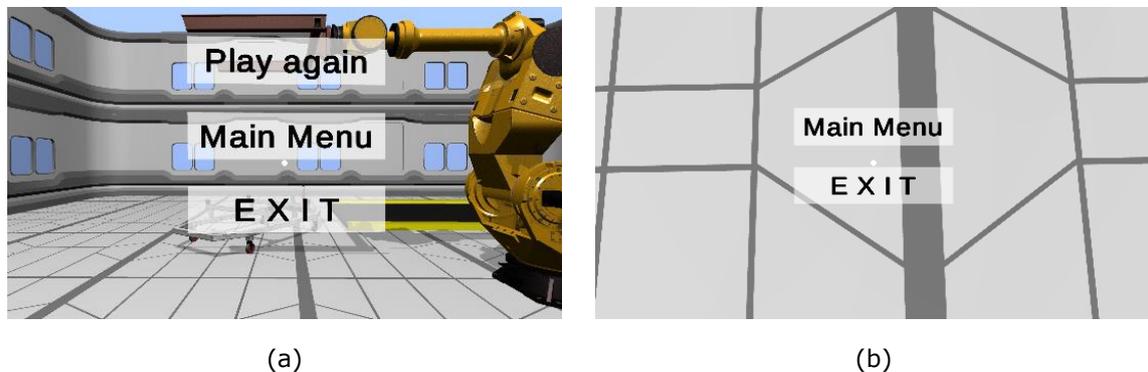
Figure 4.13. End-level menu (a) and Look-down menu (b) in VR Task 2

It is noteworthy that the vacuum cum gripper model presented in Figure 4.10 (a) was obtained from the Unity Asset Store [93].

4.2. Virtual Reality App Development

4.2.1. VR Main Menu Development

When the user starts the app, there is a fading effect from a complete dark screen to the Main Menu. The Unity scene contains a game object named "GameManager" (presented in Figure 4.14) that controls the fading in and out when the scene is started and when a new scene is loading.
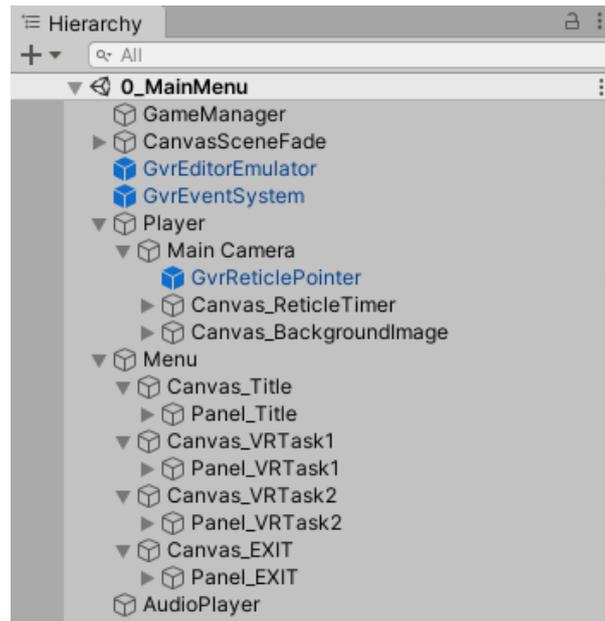
Figure 4.14. Hierarchy view of the Unity scene for the VR Main Menu

In the inspector view of the game object, the transform of the object, an audio source component and a script component are included (Figure 4.15).
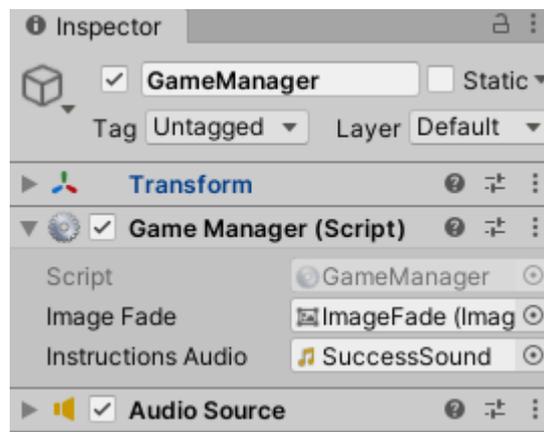
Figure 4.15. Inspector view of the Game Manager object in the application main menu

The complete "GameManager" script is available in the Appendix 2 of this thesis. This same script is utilized in other levels to control the fading in and out as well as the audio playing with the necessary instructions and explanations. In the script, the class begins with the definition of several variables. Some of them are defined inside the script, such as the float variables defining the fading time. Others are serialized fields to add other game objects from the inspector view (i.e. "ImageFade" object shown in Figure 4.15). Since the Start() method is called only once and on the frame when the script is enabled, it is utilized in this case to invoke the two methods Fade() and DisableImageFade() at the right time (see Appendix 2).

In the hierarchy view of Figure 4.14, the game object "CanvasSceneFade" contains the image used for the fading in and out. The game object "GvrEditorEmulator" gives an in-editor emulation of head movement and controller input [94] while the "GvrEventSystem" replaces the Unity's game object Event System prefab for UI [95].

The "Player" game object contains the "Main Camera", which allows to observe the environment. The later one contains the prefab "GvrReticlePointer", which gives a gaze-based reticle pointer that enables Cardboard viewer button input [96]. Essentially, it is the pointer that shows what the user is looking at. The "Canvas_ReticleTimer" object contains the 360-degree circumference that is utilized to generate the radial effect for the option selection process described in the previous section. This effect is created and controlled with the script presented in Appendix 3.
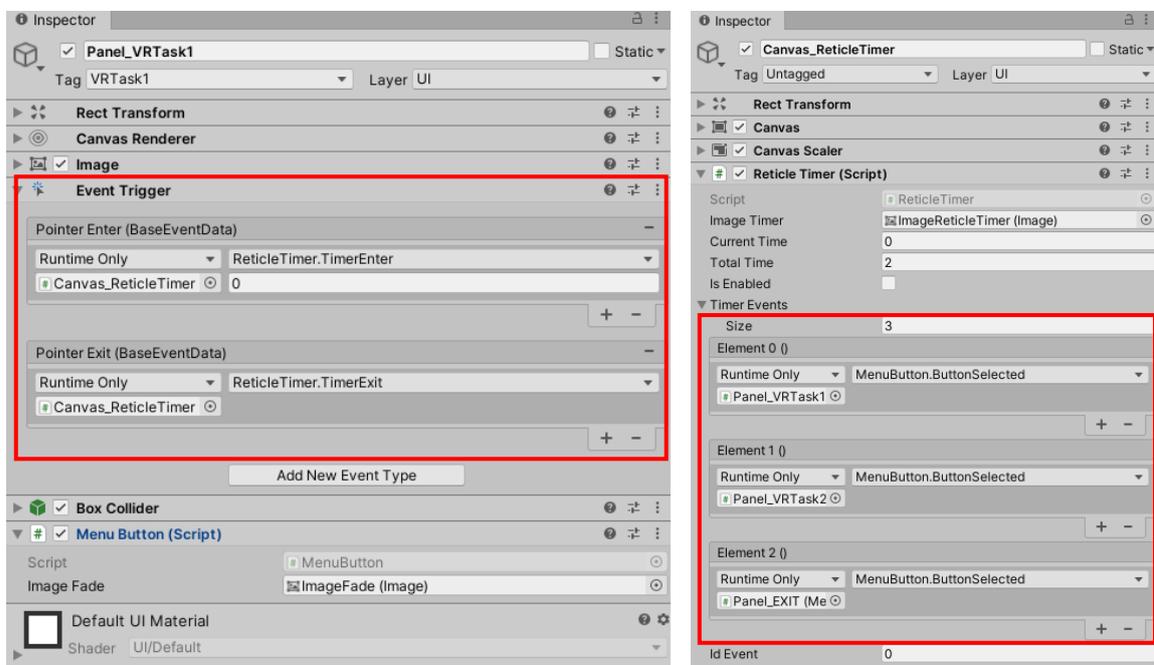
(a)   (b)

Figure 4.16. Inspector view of the "Panel_VRTask1" object (a) and Inspector view of the "Canvas_ReticleTimer" object (b)

In the script, the Timer() method defines the time for the radial effect and executes a specific event of an event array when the timer effect is finished. The event is specified in the TimerEnter() method, which reads the number specified in the game object that has been selected. This is done with an Event trigger attached to the elements that are interactable. As an example, in the inspector view of the "Panel_VRTask1" game object (Figure 4.16 (a), the event trigger component is indicating that when the pointer enters (the user hovers over the game object), the method TimerEnter() of the "ReticleTimer" script (Appendix 3) shall be called. Then, a value of 0 is passed to the array of events,

which will execute the method (or methods) specified in the element 0 of the array. This is represented in Figure 4.16 (a) and (b). As shown in Figure 4.16 (b), the size of the timer events array is three, and with the element 0, the method ButtonSelected() contained in the script "MenuButton" of the "Panel_VRTask1" game object will be executed.

The other event type included in the event trigger component of Figure 4.16 (a) is of the type "Pointer Exit". This means that when the reticle pointer exits the interactable object (in this case "Panel_VRTask1"), the TimerExit() method of the "ReticleTimer" script in the "Canvas_ReticleTimer" game object will be called.

In Figure 4.14, the "Menu" game object contains several other objects. The objects "Panel_VRTask2" and "Panel_EXIT" are built as described for "Panel_VRTask1", with the utilization of event trigger components and the timer event array presented in Figure 4.16 (b). All these three objects contain the script named "MenuButton" too, which controls their behavior. This script is presented in Appendix 4.

The last game object displayed in Figure 4.14 is named "AudioPlayer". It is used in the scene to play background music. It has an audio source component attached so that the sound is emitted. The "Main Camera" object contains an audio listener component that receives the sound at the position of the user as well as the script "GvrPointerPhysicsRaycaster", which provides a raycaster that uses raycast modes specifically for Gvr [97].

4.2.2. VR Task 1 – Animated Scene Development

Figure 4.17 (a) shows the scene hierarchy for the animated introduction of VR Task 1. The first game object is again a Game Manager. In Figure 4.17 (b), the Inspector view of this object is presented. It includes the transform (with all the position, rotation, and scale parameters of the object), an audio source component and a script. The audio source is utilized to play the audio with explanations while the animation is executing. The script "T1AnimGameManager" controls the fading in and out of the scene as well as the audios being played at the right time, to support the animated visualization displayed to the learner. The last method of the script LoadNextPartOfVRTask1(), loads the VR Task 1 interactive activity. The full script is available in Appendix 5.

(a)	(b)
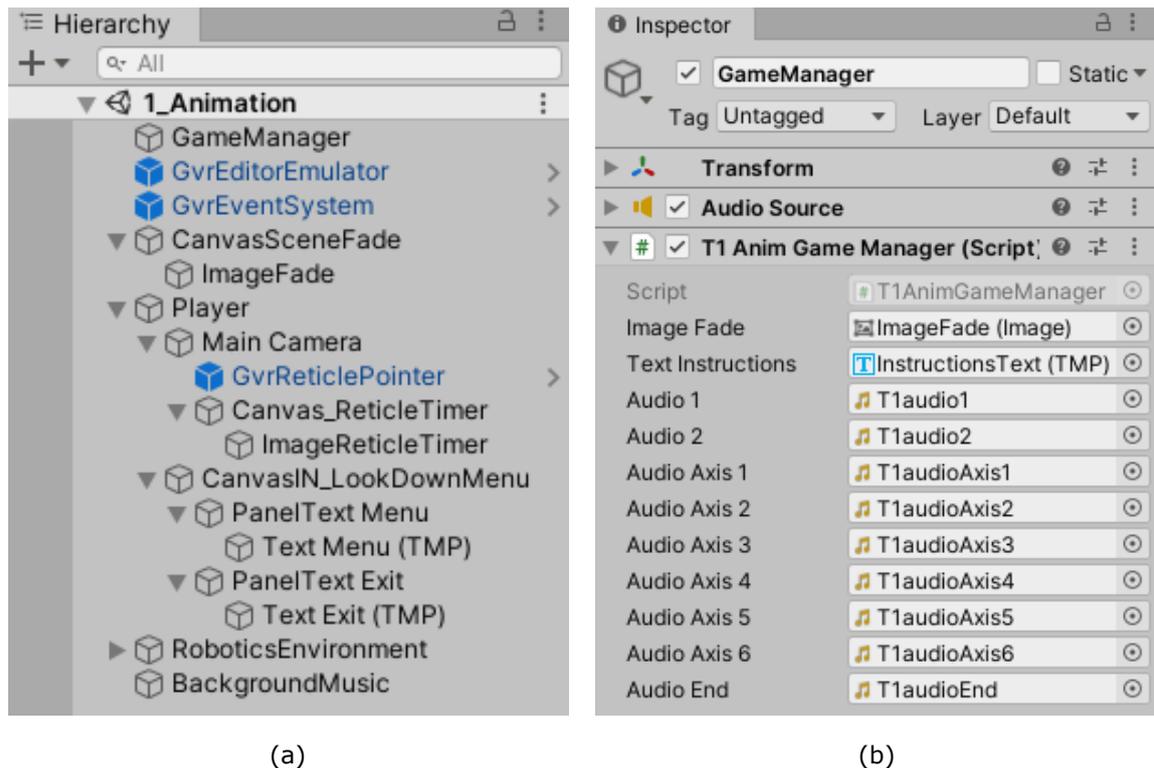
Figure 4.17. Hierarchy of the scene 1_Animation of the VR Task 1 (a) and Inspector view of the "GameManager" object in the 1_Animation scene (b)

One of the features reported in section 4.1 and graphically represented in Figure 4.7 (b) and 4.13 (b) is that, in every scene, the learner always has the option to open a menu with the options to return to the main menu or to quit the app. This is done with the game object "CanvasIN_LookDownMenu" shown in Figure 4.17 (a). The object contains the script "CanvasIN" available in Appendix 6 of this document. It has two methods, LookAtPlayer() and ApplyFadeWhenLook(), which are both continuously called from the Update() method of the script. LookAtPlayer() is a function meant to always be in front of the player (in each frame). The position and the rotation are adjusted to always be facing the user. The method ApplyFadeWhenLook() is built so that when the user looks down (to the floor), the canvas that contains both buttons of the menu fades in. If the user looks to the scene, the canvas disappears.

In Figure 4.17 (a), the game objects "PanelText Menu" and "PanelText Exit" are the interactive buttons of the menu which pops up when the user looks down. They work in the same way described before for the buttons of the Main Menu scene. For instance, in Figure 4.18 (a) the object "PanelText Menu" uses an event trigger component to indicate what function the "ReticleTimer" script (Appendix 3) must perform according to the passed value (in this case 0). This can be visualized in the timer event array displayed in Figure 4.18 (b). This is the same process as the one presented in Figure 4.16.
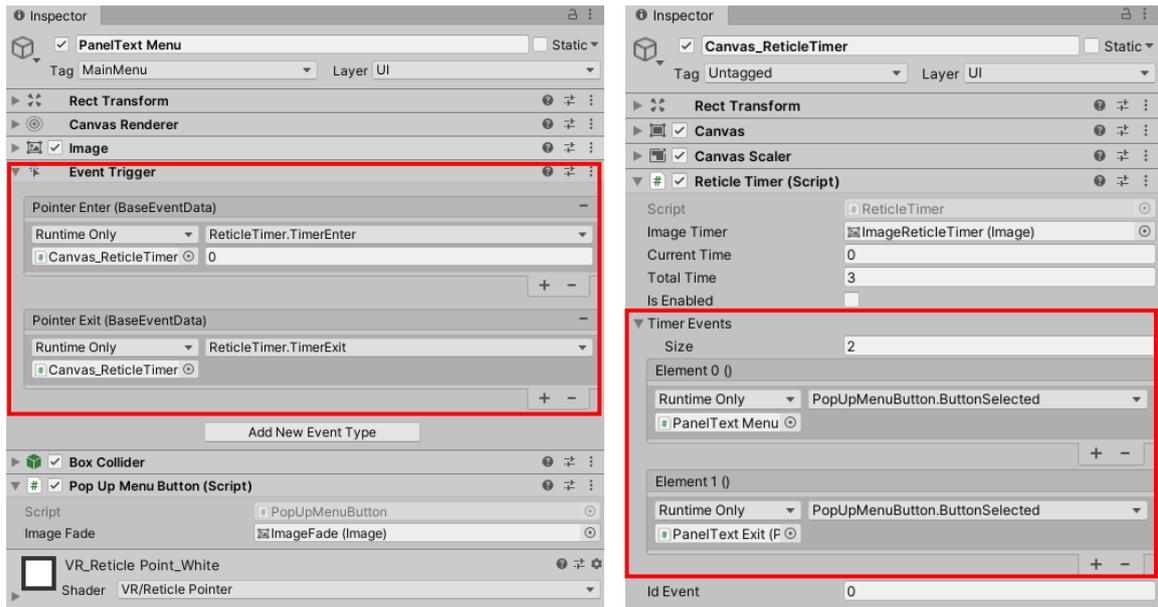
| (a) | (b) |

Figure 4.18. Inspector view of the "PanelText Menu" object (a) and Inspector view of the "Canvas_ReticleTimer" object (b)

Both "PanelText Menu" and "PanelText Exit" are controlled by the script "PopUpMenuButton" (Appendix 7). The method ButtonSelected() is the one called for each element of the array of timer events, as shown in Figure 4.18 (b). This means that when the button is selected after the 360-degree radial filling effect, the method ButtonSelected() will be executed for the specified game object in each element of the timer event array.

In Figure 4.17, the "Robotics Environment" game object contains the elements inside the scene that the learner will see. All the panel game objects contained in it have the script "ButtonAndLineController" (Appendix 8) attached, which controls their behavior. The object "BackgroundMusic" contains an audio source component that plays a melody while the animation and explanations are taking place. The animation is done by utilizing the Unity tool "Timeline". As presented in Figure 4.19, the generated track has several dots over time. The dots represent the change in the transform component of a specific game object. The result is the animation that is graphically visualized in Figure 4.3 (item 4.1.4).

Figure 4.19. Timeline used to generate the animation

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4.2.3. VR Task 1 - Immersive Environment Development

The hierarchy view presented in Figure 4.20 shows all the game objects included in the VR Task 1 scene for the immersive environment with interactive activity. The "GameManager" object controls the fading in and out and plays the audio with initial instructions when the level is started. The object contains an audio source component and a script component previously described (Appendix 2).
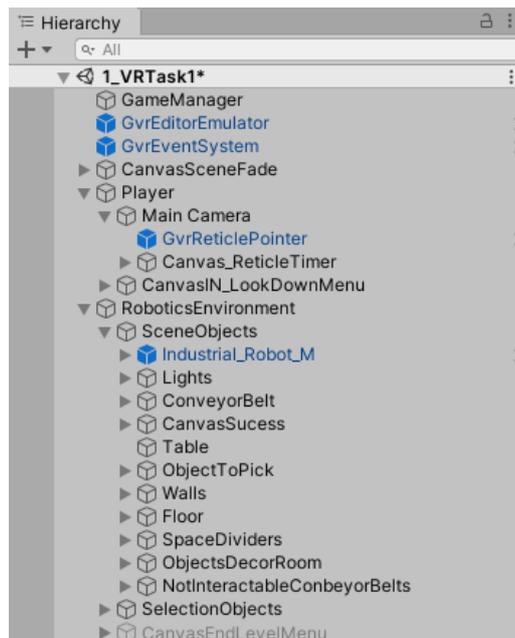
Figure 4.20. Hierarchy view of the VR Task 1 immersive environment

The object "Canvas_ReticleTimer" controls again the behavior of most elements once the user interacts with them. The utilization of an array of timer event elements in combination with the functionality generated by the script component "ReticleTimer" (Appendix 3) is present in this scene again. The "CanvasIN_LookDownMenu" object is included in the scene to enable the learners to quit the app or return to the main menu when desired, as previously elaborated.

Under the objects "Robotics Environment" and "SceneObjects", the prefab "Industrial_Robot_M" is the actual robot model used in this scene (as explained in item 4.1.5). This game object contains the script "RobotController", the component responsible for the behavior of the robot. The full script is available in Appendix 9. It contains several declared serialized field variables to make them available in the inspector view. The variables hold the transform components of the different parts of the robot that must be controlled by the user. In the script, the method PerformRotation() is given a parameter that is used to generate motion in the right joint

by using a switch statement and the Rotate() function. It is important to note that it is rotated with a speed defined as a variable (named "rotationSpeed") inside the script and multiplied by the property "Time.deltaTime". By doing this, it is ensured that the rotation speed is always the same, no matter what device is running the virtual reality application. This is because "Time.deltaTime" gives the completion time in seconds since the last frame. Finally, the method AdjustSpeed() is constantly updating the speed to the value set by the user when the knob of the slider shown in Figure 4.4 (a) is repositioned.

As described in item 4.1.5 and presented in Figure 4.4 (a) and (b), the robot has a laser attached to the gripper game object. The gripper object is named "Controller_Claw_Snapping_Tool" and it is displayed in Figure 4.21 (a). As shown in the figure, the laser is generated with a script and a line renderer component. The complete script can be found in Appendix 10. The script gets the line renderer component in the Start() method and it is then controlled from the code. In the method ThrowLaser(), a ray is generated that goes from the gripper position to infinity. The method systematically checks for collisions with object colliders and if one is found, the line is drawn to the point where the object and the ray collided.

(a)   (b)
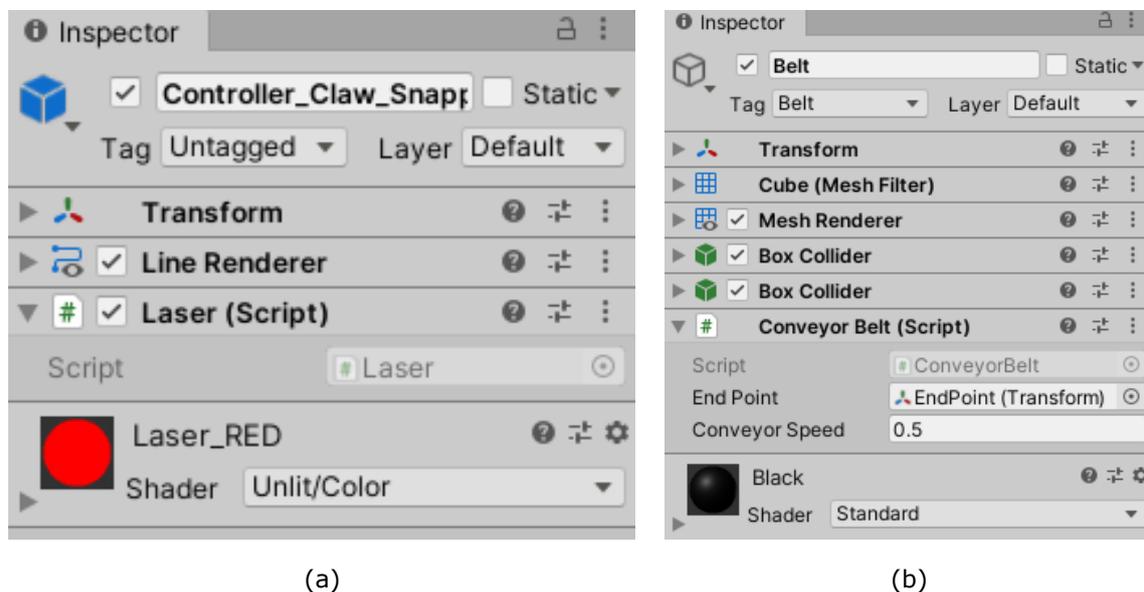
Figure 4.21. Inspector view of the "Controller_Claw_Snapping_Tool" object (a) and Inspector view of the "Belt" object included in the "ConveyorBelt" game object (b)

In Figure 4.21 (b) the belt object inspector view of the conveyor belt shown in Figure 4.6 (b) is displayed. It uses a script to transport any object that is placed on it. The script is available in Appendix 11.

The game object "ObjectToPick" presented in Figure 4.20 is also controlled with the script "ObjectToPick" (Appendix 12) that detects the collision with other game object colliders. If the collided game object contains the tag "Belt", a message is displayed to the user indicating that the task was successfully completed, as shown in Figure 4.6 (a). Then, the script executes the method DisplayEndLevelMenu() to show the menu at the end of the level which will enable the user to play again the current level, return to the main menu or quit the app. These three options are game objects of the type panel, contained in the object "CanvasEndLevelMenu". They are controlled by the script "PopUpMenuButton" available in Appendix 7 as well as by event trigger components, previously described.

Figure 4.22 (a) shows the "SelectionObjects" object hierarchy. The first element corresponds to the slider that the learner utilizes after an axis or the gripper has been selected. Moving the knob will create motion.

(a)   (b)
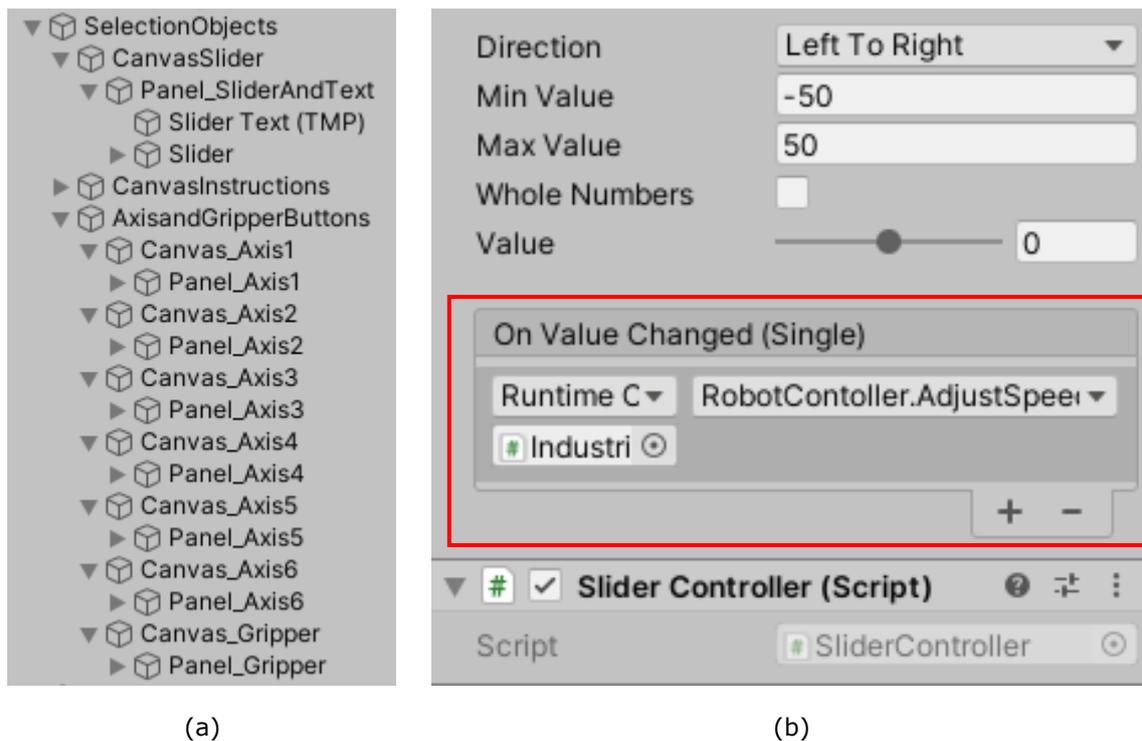
Figure 4.22. Hierarchy view of the "SelectionObjects" object (a) and Inspector view of the "Slider" game object (b)

Figure 4.22 (b) shows the Inspector view of the "Slider" game object. When the value of the slider is changed by the user, OnValueChanged() calls the method AdjustSpeed(). The later one is executed from the RobotController script attached to the robot prefab, previously described. The "SliderController" script (Appendix 13) throws a ray from the user's position in the VR environment that goes to infinity. If the ray collides with a

game object tagged as "Slider" the value of the slider is changed by using a linearizing function. The linearization is performed with the minimum and maximum values defined in Figure 4.22 (b) and a maximum and minimum value specified for the x component of the collision point in space.

Figure 4.23 (a) presents the inspector view of the game object "Panel_Axis1". When the user hovers over this element, a line points to the actual axis of the robot, as described in item 4.1.5 and Figure 4.5 (a). Therefore, the event trigger contains also an event for the line when the pointer enters and exits ("AxisLine.EnableWhiteLine" and "AxisLine.DisableLine"). To control both the axis button and the axis line, two scripts are attached as components of the object. The first one "AxisButtonController", is available in Appendix 14 and the second one, "AxisLine" is provided in Appendix 15.
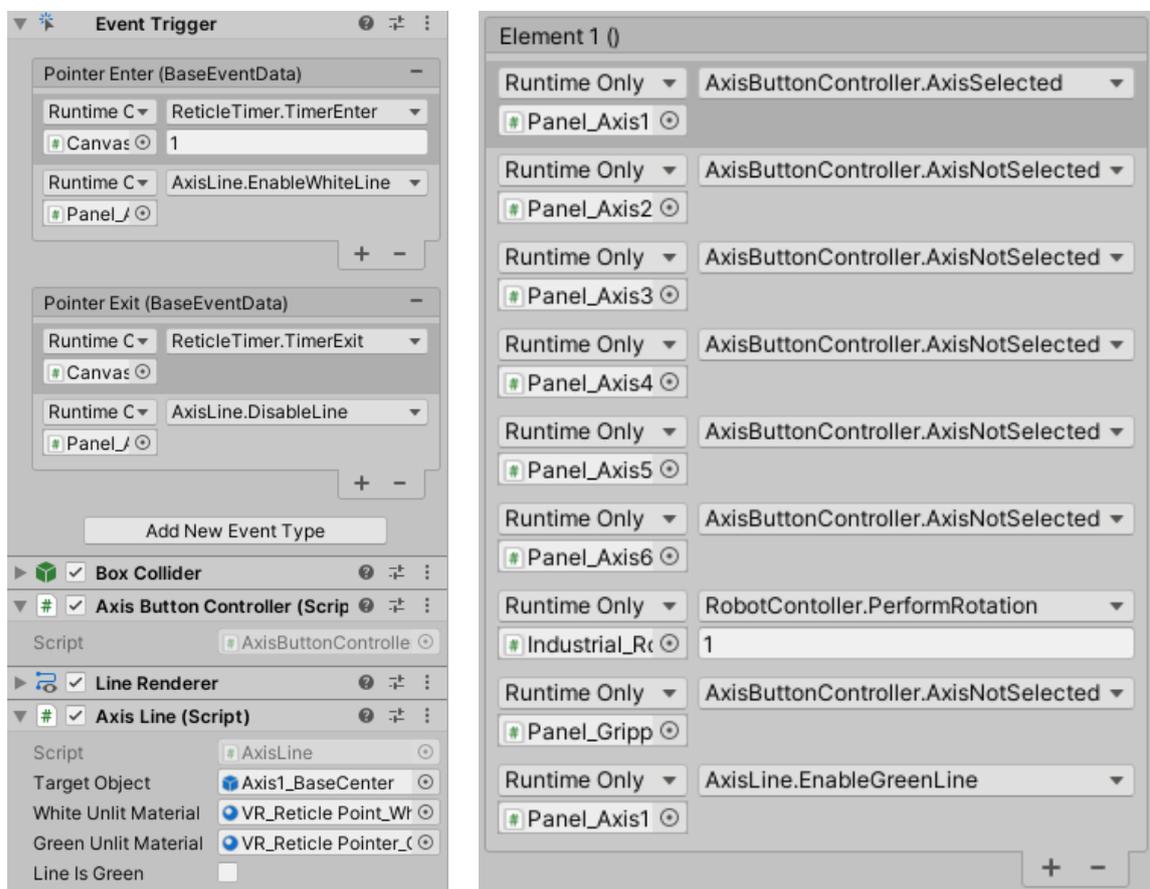
(a)   (b)

Figure 4.23. Inspector view of the game object "Panel_Axis1" (a) and part of the Inspector view of the "Canvas_ReticleTimer" (b)

With the use of the event trigger component in Figure 23 (a), the button can be selected and unselected adequately. When the pointer enters, the TimerEnter() function of the "ReticleTimer" script is called and the value of one is passed. This value lets the timer

event array know that the functions specified in first element must be executed. Figure 4.23 (b) shows the element one of the array in detail. When the "Panel_Axis1" object is selected, the other axis buttons are immediately unselected, the axis line in "Panel_Axis1" turns green to indicate that it has been selected and a value of one is passed as a parameter to the PerformRotation() method of the "RobotController" script. Thus, when the user then changes the knob position of the slider, the axis that corresponds to the last selection made by the user will begin to rotate.

4.2.4. VR Task 2 - Immersive Environment Development

In Figure 4.24 (a), the hierarchy view of the VR Task 2 is presented. The objects present in this hierarchy that have been previously shown in the other scenes will not be explained. A description of them can be found in previous items of this work. "SelectionObjects" contains the game objects that are involved in the selection process to pick the right tool for the activity proposed.

(a)   (b)
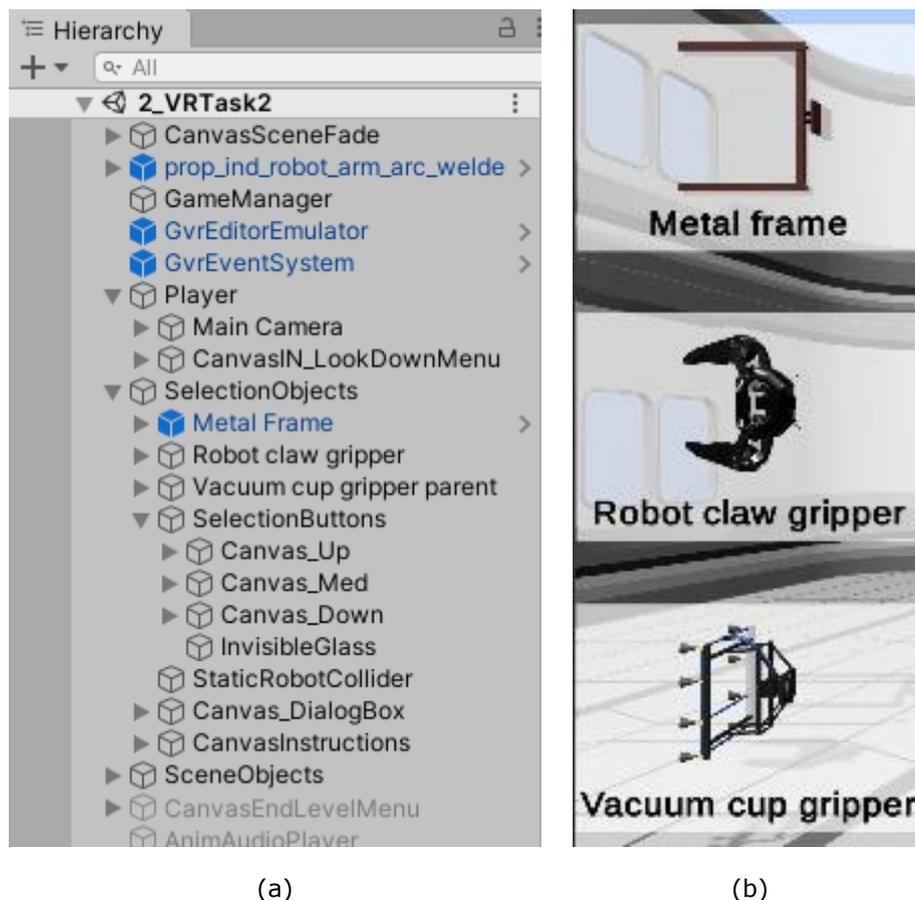
Figure 4.24. Hierarchy of the scene VR Task 2 (a) and some of the game objects involved in the tool selection process (b)

When the user hovers over one of the objects shown in Figure 4.24 (b), the selection process is started. This is done with the game objects "Canvas_Up", "Canvas_Med" and "Canvas_Down". All of them contain a panel game object that is utilized for the interaction with the user. Those panels, just as the ones that included in previous scenes, use event triggers to generate the required functionality to interact with the learner. The panel objects also include the script "SelectionButtonController" provided in Appendix 16, which contains several methods to enable the selection, change the tool size when it is chosen, undo the selection, show a dialog box when the object is being unselected, and more. The details and the logic of the class can be further reviewed in Appendix 16. It is worth mentioning that there is also a method that throws a ray from the user position in the game to infinity, and checks for collisions with the object "InvisibleGlass" of Figure 4.24 (a). This enables to drag the object to the robot since it updates the position of the tool to the point in space where the ray and the "InvisibleGlass" object collide. Figure 4.25 (a) shows the ray (blue color) colliding with the "InvisibleGlass" object and the position of the tool being updated to the spatial coordinates of the collision point in space.

(a)   (b)
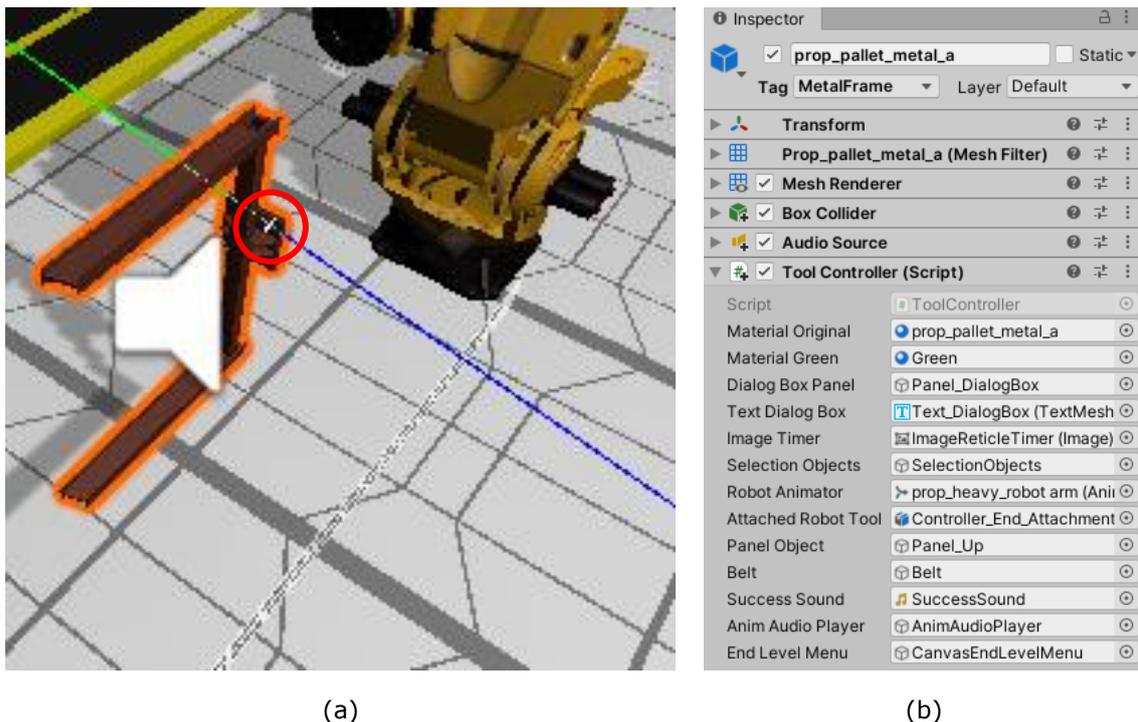
Figure 4.25. Ray (blue color) colliding with the "InvisibleGlass" object collider and updating the selected tool position (a) and the "Metal Frame" game object child containing the necessary functionality to control the tool (b)

The three different tool objects shown in Figure 4.24 (b) contain their own colliders to detect the collision with other objects of the scene. The script "ToolController" is used to control the behavior of the tool as well as other elements of the scene, such as

"Panel_DialogBox" under the object "Canvas_DialogBox". The full script is available in Appendix 17. The methods contained in the class, enable to start the tool attaching sequence of Figure 4.10 (a), display messages whether the tool is correctly selected or not, reposition of the tool object to the original position in the left are of the screen, begin the animation when the tool is correctly selected (Figure 4.12), and display the end-level menu.

"Panel_DialogBox" contained under the game object "Canvas_DialogBox" presented in Figure 4.24 (a), uses the script "DialogBoxController" to always maintain the position of the object in front of the user and on the right place so that it does not overlap with any important scene objects. The script is provided in Appendix 18.

As described for the previous scenes, a large portion of this level functionality is built in the "Canvas_ReticleTimer" game object (its "ReticleTimer" script is available in Appendix 3) presented in Figure 4.24 (a). It utilizes a timer event array to execute the public methods of different scripts when required. Other objects and their scripts previously explained are also utilized in this scene, like "Canvas_INLookDownMenu" (its "CanvasIN" script is available in Appendix 6) and the child panel objects with their scripts "PopUpMenuButton" (available in Appendix 7). Also, the panel objects contained in the "CanvasEndLevelMenu" have the "PopUpMenuButton" script component attached, enabling the learner to play the same level, return to the main menu or quit the app, just as reported for the VR Task 1 scene.

4.3. Flowchart logic representation of the VR scenes

In order to give a clearer representation of the logic behind each VR scene, flowcharts have been created for the Main Menu, the VR Task 1 and the VR Task 2 scenes.

For instance, the flowchart represented in Figure 4.26 presents the logic of the Main Menu scene. This diagrammatic representation of the algorithm can also be found in Appendix 19. Due to the large dimensions of the flowcharts for VR Task 1 and VR Task 2, they are not included in the main body of the thesis. Nevertheless, both diagrams are provided in Appendix 20 and Appendix 21, respectively.
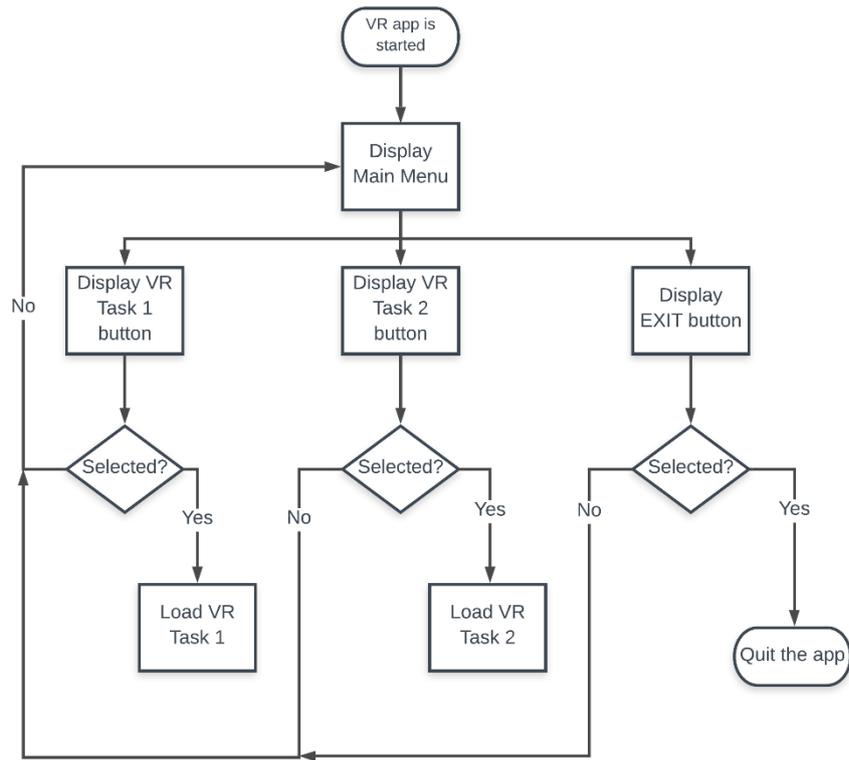
Figure 26. Flowchart representation of the logic behind the Main Menu scene

4.4. Generated App

After all the previously mentioned functionality was developed, the app was generated. The result is a usable application that users can download and utilize comfortably with their own mobile or tablet devices, thus achieving the expected outcome. Figure 4.27 (a) shows the MILAN VR app installed on a mobile device. The app being used with a mobile device is shown in Figure 4.27 (b).
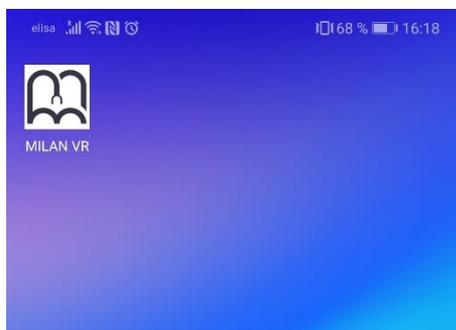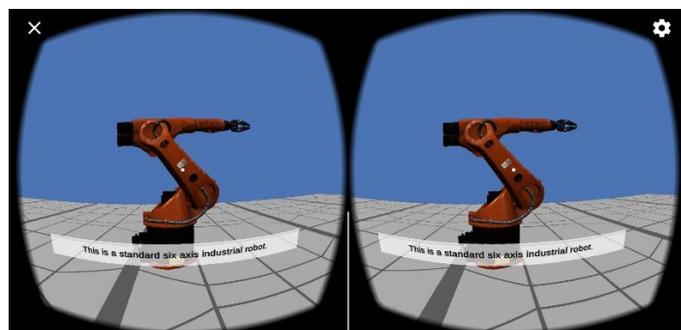
(a)   (b)

Figure 4.27. MILAN VR app installed on a mobile device ready to be used (a) and utilization of the app on a mobile device (b)

4.5. Chapter 4 - Concluding remarks

It is important to note that the VR tasks included in this application represent only an example of how virtual reality can be implemented in the field of robotics and automation. Diverse VR environments can be designed and developed to meet the learners' needs for each topic. These are only some examples related to the topics covered in the MILAN research project. It is also worth mentioning that, although more VR tasks could be included in the future, this work helped to test how easily virtual reality could be combined with e-learning platforms.

5. SUMMARY

5.1. Conclusion

The result of this work is a usable virtual reality application for robotics and automation education as well as an e-learning environment design, specifically created to merge with virtual reality and generate strong study habits. The outcome of this work is built upon solid foundations obtained from a deep analysis of literature. These foundations are based on the current understanding of human learning, e-learning environments, habit-forming techniques and, virtual and augmented reality usage in the fields of robotics, automation, manufacturing and industrial safety.

The cross-platform game engine Unity, the integrated development environment Microsoft Visual Studio, as well as the programming language C# were critical for the correct development of this work.

The performed thesis development process allowed to initially break down the problem, implement a deep analysis of its key elements and use fundamental conclusions to later design the e-learning environment and develop the VR application. By doing so, it was possible to successfully achieve the initially defined objectives. The outcome of this work shows that e-learning environments can hook the users into learning by utilizing the right habit-forming elements. In addition, this thesis describes how virtual reality applications can be easily merged with e-learning, reaching all learners and reducing the cost for the user to practically zero.

In brief, the proposed e-learning environment design and VR application represent an effective synergy that can have a profound positive impact in students' academic performance. Thus, the author suggests using the provided approach in the MILAN research project as well as in other future e-courses supported by virtual reality.

5.2. Limitations of the research

The virtual reality environment created can be used with mobile devices and covers the needs of the user. It is immersive, interactive, supports learning and the cost is practically zero. However, the learner has no VR controllers, and thus the interactive part of the experience could be reduced. The VR solution can be exported to work in different platforms to be usable with professional VR headsets, such as Oculus Rift or

HTC Vive. This can enhance the virtual reality experience for those who own these devices. However, for those learners without this option, the interactive experience may be reduced.

5.3. Future scope

In the following years, smartphones may include LIDAR sensors. At this point in time, the company Apple has already launched the new iPad Pro with a LIDAR scanner [98]. This technology can build 3D maps of the surroundings. Therefore, if the user placed the hands in front of the VR headset, the LIDAR sensor in the mobile device could be used to reconstruct a 3D model of them inside the virtual reality environment. This technology would enable learners to directly interact with the virtual elements without the use of controllers, enhancing the immersion and the interactive experience and eliminating the barrier described in section 5.2.

6. KOKKUVÕTE

6.1. Järeldused

Käesoleva töö tulemusena valmisid kasutamiskõlblik virtuaalreaalsusel põhinev rakendus, mis on mõeldud robootika ja automaatika valdkonna õppimiseks, ning e-kursuse keskkonna disain. Viimane on loodud spetsiaalselt virtuaalsereaalsusega sulandumiseks ja tugevate õpiharjumuste loomiseks. Töö tulemused on üles ehitatud tugevatele alustele, mis on saadud põhjalikust kirjanduse analüüsist. Need alused põhinevad praegusel arusaamal inimeste õppimisviisidest, e-õppe keskkondadest, harjumust kujundavatest tehnikatest ning virtuaal- ja augmenteeritud reaalsuse kasutusest robootika, automaatika ja tootmise valdkondades ning tööohutuses.

Töö korrektseks arenguks olid olulised integreeritud loomevahend Unity, integreeritud arenduskeskkond Microsoft Visual Studio ning programmeerimiskeel C#.

Uurimistöö protsessi käigus autor esialgu mõtestas lahti probleemi ning teostas probleemi põhielementide süvaanalüüsi. Viimasest tulenevalt tegi autor fundamentaalsed järeldused, et hiljem disainida e-õppe keskkond ning arendada virtuaalreaalsusel põhinev rakendus. Nii toimides oli võimalik algselt määratletud eesmärgid edukalt saavutada. Selle töö tulemus näitab, et e-õppe keskkonnad saavad kasutajaid õigete harjumusi kujundavate elementide abil õppimisse siduda. Lisaks kirjeldab käesolev lõputöö, kuidas virtuaalreaalsusel põhinevaid rakendusi saab hõlpsasti e-õppega ühendada, jõudes kõigi õppijateni ja vähendades kasutaja kulusid praktiliselt nullini.

Lühidalt, väljapakutud e-õppe keskkonna disain ja virtuaalreaalsusel põhinev rakendus esindavad tõhusat sünergiat, millel võib olla sügav mõju üliõpilaste akadeemilistele sooritustele. Seetõttu soovitab autor kasutada esitatud lähenemisviisi nii MILAN-i uurimisprojekti kui ka teiste tulevaste virtuaalreaalsusele toetuvate e-kursuste puhul.

6.2. Uurimistöö piirangud

Loodud virtuaalreaalsuse keskkonda saab kasutada koos mobiilseadmetega ja see katab kasutaja vajadused. See on süüviv, interaktiivne, toetab õppimist ning selle hind on nullilähedane. Seevastu ei ole õppuril virtuaalreaalsuse kontrollseadmeid ja seetõttu võib kogemuse interaktiivne osa väheneda. Väljatöötatud virtuaalreaalsuse lahendust

on võimalik eksportida loomevahendist Unity, et see töötaks ka teistel platvormidel ning et seda saaks kasutada professionaalsete VR prillide, nt Oculus Rift ja HTC Vive, puhul. Neil, kellel on professionaalsed seadmed, võib esineda paremat virtuaalreaalsuse kogemust, võrreldes õppijatega, kellel see võimalus puudub.

6.3. Tuleviku väljavaated

Järgnevatel aastatel võivad nutitelefonid sisaldada LIDAR-andureid. Praeguseks on ettevõte Apple juba turule lasknud uue LIDAR-skänneriga iPad Pro [96]. See tehnoloogia võimaldab luua ümbrusest 3D-kaarte. Seega, kui kasutaja asetaks käed VR-prillide ette, saaks mobiilseadmes olevat LIDAR-andurit kasutada käte 3D-mudeli rekonstrueerimiseks virtuaalreaalsuse keskkonnas. Selline tehnoloogia võimaldaks õppijatel virtuaalsete elementidega vahetult suhelda, ilma kontrollseadmeid kasutamata, parandades seeläbi süüvimist ja interaktiivset kogemust ning kõrvaldades punktis 5.2 kirjeldatud takistuse.

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APPENDICES

MILAN

Forum   Contact   F.A.Q

My Username
Account details

Robotics and Automation in Advanced Manufacturing
Block 1: Advanced Manufacturing and 3D Printing

Course completion: 0%
Grade: 0/100

0/110 completed sections

Progress Area

Completed sections / Day

Day

0 Day Strike

Unlock grade reward with a 2 Day Strike

Start

Block 1: Advanced Manufacturing and 3D Printing

Block 2: Robotics in Industry

Block 3: Industry 4.0 and VR and AR Applications in Manufacturing

Block 4: Safety, Standards and Certification in Manufacturing

Exam

Certificate: Congratulations! You finished the course!

Module 1: Advanced Manufacturing

1.1.1. Learn: Introduction to Advanced Manufacturing ⊕

1.1.2. Practice: Advanced Manufacturing Fundamentals ⊕

1.1.3. Learn: Sample Text Sample Text Sample Text ⊕

1.1.4. Practice: Sample Text Sample Text Sample Text Sample Text ⊕

1.1.5. Remember: Sample Text Sample Text Sample Text Sample Text ⊕

1.1.6. Learn: Sample Text Sample Text Sample Text Sample Text ⊕

1.1.7. Practice: Sample Text Sample Text Sample Text Sample Text ⊕

1.1.8. Remember: Sample Text Sample Text Sample Text Sample Text ⊕

1.1.9. Experiment: Sample Text Sample Text Sample Text ⊕

1.1.10. Project: Sample Text Sample Text Sample Text ⊕

Module 2: 3D Printing

1.2.1. Learn: Sample Text Sample Text Sample Text Sample Text ⊕

MILAN

Robotics and Automation in Advanced Manufacturing
Block 1: Advanced Manufacturing and 3D Printing
1.1.2. Practice: Advanced Manufacturing Fundamentals

Forum   Contact   F.A.Q

My Username
Account details

Course completion: 0.9%
Grade: 0.25/100

1/110 completed sections

Start

Block 1: Advanced Manufacturing and 3D Printing

Block 2: Robotics in Industry

Block 3: Industry 4.0 and VR and AR Applications in Manufacturing

Block 4: Safety, Standards and Certification in Manufacturing

Exam

Certificate: Congratulations! You finished the course!

1.1.2. Practice: Advanced Manufacturing Fundamentals ⊕ Add section notes

Proposed exercise

Section resources:

→] Download problem in PDF format

→] Download solution in PDF format

→] Download solution in video format

Answer to Q1:

Answer to Q2:

Answer to Q3:

Answer to Q4:

Check Answers

If answers are correct, the section will be marked as finished and you will unlock a grade reward

Watch solution in video format

MILAN

Forum   Contact   F.A.Q

My Username
Account details

Robotics and Automation in Advanced Manufacturing
Block 1: Advanced Manufacturing and 3D Printing
1.1.3. Learn: Sample Text Sample Text Sample Text

Course completion: 1.8%
Grade: 0.72/100

2/110 completed sections

Start

Block 1: Advanced Manufacturing and 3D Printing

Block 2: Robotics in Industry

Block 3: Industry 4.0 and VR and AR Applications in Manufacturing

Block 4: Safety, Standards and Certification in Manufacturing

Exam

Certificate: Congratulations! You finished the course!

1.1.3. Learn: Sample Text Sample Text Sample Text ⊕ Add section notes

✕

Mark section as finished ➤
You will unlock a grade reward

Section resources:

➡ Download section in video format

➡ Download section in PDF format

7 Comments

My Username
Add a comment to the discussion

Username X
Sample Question Sample Question Sample Question?
3 👍 Reply   View replies ▶

Robotics and Automation in Advanced Manufacturing
Block 1: Advanced Manufacturing and 3D Printing

Forum   Contact   F.A.Q

My Username
Account details

Course completion: 2.7%

Grade: 1.07/100

3/110 completed sections

Progress Area

Completed sections / Day

Day

2 Day Strike

Unlock grade reward with a 4 Day Strike

Module 1: Advanced Manufacturing

1.1.1. Learn: Introduction to Advanced Manufacturing ⊕

1.1.2. Practice: Advanced Manufacturing Fundamentals ⊕

1.1.3. Learn: Sample Text Sample Text Sample Text Sample Text ⊕

1.1.4. Practice: Sample Text Sample Text Sample Text Sample Text ⊕

1.1.5. Remember: Sample Text Sample Text Sample Text Sample Text ⊕

1.1.6. Learn: Sample Text Sample Text Sample Text Sample Text ⊕

1.1.7. Practice: Sample Text Sample Text Sample Text Sample Text ⊕

1.1.8. Remember: Sample Text Sample Text Sample Text Sample Text ⊕

1.1.9. Experiment: Sample Text Sample Text Sample Text ⊕

1.1.10. Project: Sample Text Sample Text Sample Text ⊕

Module 2: 3D Printing

1.2.1. Learn: Sample Text Sample Text Sample Text Sample Text ⊕

Start

Block 1: Advanced Manufacturing and 3D Printing

Block 2: Robotics in Industry

Block 3: Industry 4.0 and VR and AR Applications in Manufacturing

Block 4: Safety, Standards and Certification in Manufacturing

Exam

Certificate: Congratulations! You finished the course!

MILAN

```csharp
using UnityEngine;
using UnityEngine.UI;

public class GameManager : MonoBehaviour
{
    AudioSource audioSource;
    [SerializeField] Image imageFade;
    [SerializeField] AudioClip instructionsAudio;

    float timeToStartFading = 0.25f;
    float timeFading = 1.25f;

    // Start is called before the first frame update
    void Start()
    {
        audioSource = GetComponent<AudioSource>();
        imageFade.enabled = true;
        Invoke("Fade", timeToStartFading);
        Invoke("DisableImageFade", timeToStartFading + timeFading);
    }

    private void Fade()
    {
        imageFade.CrossFadeAlpha(0f, timeFading, true);
    }

    private void DisableImageFade()
    {
        audioSource.PlayOneShot(instructionsAudio);
        imageFade.enabled = false;
    }
}
```

```csharp
using UnityEngine;
using UnityEngine.UI;
using UnityEngine.Events;

public class ReticleTimer : MonoBehaviour
{
    [SerializeField] Image imageTimer;
    [SerializeField] float currentTime = 0f;
    [SerializeField] float totalTime = 3f;
    [SerializeField] bool isEnabled = false;
    [SerializeField] UnityEvent[] timerEvents;
    [SerializeField] int idEvent;

    // Start is called before the first frame update
    void Start()
    {
        TimerExit();
    }

    // Update is called once per frame
    void Update()
    {
        Timer();
    }

    private void Timer()
    {
        if (isEnabled)
        {
            currentTime += Time.deltaTime;
            imageTimer.fillAmount = currentTime / totalTime;

            if (currentTime >= totalTime)
            {
                TimerExit();
                timerEvents[idEvent].Invoke();
            }
        }
    }

    public void TimerEnter(int _idVar)
    {
        isEnabled = true;
        idEvent = _idVar;
    }

    public void TimerExit()
    {
        isEnabled = false;
        imageTimer.fillAmount = 0f;
        currentTime = 0f;
    }
}
```

```csharp
using UnityEngine;
using UnityEngine.SceneManagement;
using UnityEngine.UI;

public class MenuButton : MonoBehaviour
{
    [SerializeField] Image imageFade;
    Image panelImage;
    Color colorGreen;
    Color colorWhiteTransparent;
    float timeFading = 1.5f;

    private void Start()
    {
        panelImage = GetComponent<Image>();
        colorGreen = new Color(0, 255, 0, 1);
        colorWhiteTransparent = new Color(255, 255, 255, 0.686f);
    }

    public void ButtonSelected()
    {
        panelImage.color = colorGreen;
        StartVRTaskLoadingSequence();
    }

    public void ButtonNotSelected()
    {
        panelImage.color = colorWhiteTransparent;
    }

    private void StartVRTaskLoadingSequence()
    {
        Fade();
        switch (gameObject.tag)
        {
            case "VRTask1":
                Invoke("LoadFirstVRTask", timeFading);
                break;
            case "VRTask2":
                Invoke("LoadSecondVRTask", timeFading);
                break;
            case "Exit":
                Invoke("ExitApp", timeFading);
                break;
            default:
                break;
        }
    }

    private void Fade()
    {
        imageFade.canvasRenderer.SetAlpha(0f);
        imageFade.enabled = true;
        imageFade.CrossFadeAlpha(1f, timeFading, false);
    }

    private void LoadFirstVRTask()
    {
        SceneManager.LoadScene(1);
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```csharp
        }

    private void LoadSecondVRTask()
    {
        SceneManager.LoadScene(3);
    }

    private void ExitApp()
    {
        Application.Quit();
    }
}
```

```csharp
using UnityEngine;
using UnityEngine.UI;
using TMPro;
using UnityEngine.SceneManagement;

public class T1AnimGameManager : MonoBehaviour
{
    AudioSource audioSource;
    [SerializeField] Image imageFade;
    [SerializeField] TextMeshProUGUI textInstructions;
    [SerializeField] AudioClip audio1;
    [SerializeField] AudioClip audio2;
    [SerializeField] AudioClip audioAxis1;
    [SerializeField] AudioClip audioAxis2;
    [SerializeField] AudioClip audioAxis3;
    [SerializeField] AudioClip audioAxis4;
    [SerializeField] AudioClip audioAxis5;
    [SerializeField] AudioClip audioAxis6;
    [SerializeField] AudioClip audioEnd;

    string text1 = "This is a standard six axis industrial robot.";
    string text2 = "That means that the robot can rotate on six different axes.";
    string text3 = "Axis 1";
    string text4 = "Axis 2";
    string text5 = "Axis 3";
    string text6 = "Axis 4";
    string text7 = "Axis 5";
    string text8 = "And Axis 6";
    string text9 = "Great. Now let's get some practice!";
    float timeToStartFading = 0.25f;
    float timeFading = 1.25f;
    float t0 = 5.15f;
    float t1 = 9.5f;
    float t2 = 15f;
    float t3 = 20.5f;
    float t4 = 27.5f;
    float t5 = 33f;
    float t6 = 37.5f;
    float t7 = 43.5f;
    float t8 = 46f;

    // Start is called before the first frame update
    void Start()
    {
        audioSource = GetComponent<AudioSource>();
        imageFade.enabled = true;
        Invoke("Fade", timeToStartFading);
        Invoke("DisableImageFade", timeToStartFading + timeFading);
        Invoke("PlayAudio2", t0);
        Invoke("PlayAudioAxis1", t1);
        Invoke("PlayAudioAxis2", t2);
        Invoke("PlayAudioAxis3", t3);
        Invoke("PlayAudioAxis4", t4);
        Invoke("PlayAudioAxis5", t5);
        Invoke("PlayAudioAxis6", t6);
        Invoke("PlayAudioEnd", t7);
        Invoke("LoadNextPartOfVRTask1", t8);
    }
```

```csharp
private void Fade()
{
    imageFade.CrossFadeAlpha(0f, timeFading, true);
}

private void DisableImageFade()
{
    audioSource.PlayOneShot(audio1);
    imageFade.enabled = false;
    textInstructions.text = text1;
}

private void PlayAudio2()
{
    audioSource.PlayOneShot(audio2);
    textInstructions.text = text2;
}

private void PlayAudioAxis1()
{
    audioSource.PlayOneShot(audioAxis1);
    textInstructions.text = text3;
}

private void PlayAudioAxis2()
{
    audioSource.PlayOneShot(audioAxis2);
    textInstructions.text = text4;
}

private void PlayAudioAxis3()
{
    audioSource.PlayOneShot(audioAxis3);
    textInstructions.text = text5;
}

private void PlayAudioAxis4()
{
    audioSource.PlayOneShot(audioAxis4);
    textInstructions.text = text6;
}

private void PlayAudioAxis5()
{
    audioSource.PlayOneShot(audioAxis5);
    textInstructions.text = text7;
}

private void PlayAudioAxis6()
{
    audioSource.PlayOneShot(audioAxis6);
    textInstructions.text = text8;
}

private void PlayAudioEnd()
{
    audioSource.PlayOneShot(audioEnd);
    textInstructions.text = text9;
}

private void LoadNextPartOfVRTask1()
{
```

```
        int currentSceneIndex = SceneManager.GetActiveScene().buildIndex;
        int nextSceneIndex = currentSceneIndex + 1;
        SceneManager.LoadScene(nextSceneIndex);
    }
}
```

```csharp
using UnityEngine;
[RequireComponent(typeof(CanvasGroup))]

public class CanvasIN : MonoBehaviour
{
    Camera mainCamera;
    CanvasGroup mainCanvasGroup;
    [Range(0, 5)] [SerializeField] float fadingDuration = 1f;
    private float alphaVar = 0f;

    private void Awake()
    {
        mainCamera = Camera.main;
        mainCanvasGroup = GetComponent<CanvasGroup>();
    }

    void Update()
    {
        LookAtPlayer();
        ApplyFadeWhenLook();
    }

    private void LookAtPlayer()
    {
        Vector3 upDirection = (mainCamera.transform.up +
        mainCamera.transform.forward) / 2;
        Vector3 forwardDirection = new Vector3(upDirection.x, 0, upDirection.z);
        forwardDirection.Normalize();
        transform.position = mainCamera.transform.position - (Vector3.up * 100f) +
        forwardDirection;
        Vector3 vectorToCamera = mainCamera.transform.position - transform.position;
        float distanceToCamera = vectorToCamera.magnitude;

        if (distanceToCamera > mainCamera.nearClipPlane)
        {
            transform.rotation =
            Quaternion.LookRotation(mainCamera.transform.forward,
            mainCamera.transform.up);
        }
    }

    private void ApplyFadeWhenLook()
    {
        Vector2 viewPortPoint = mainCamera.WorldToViewportPoint(transform.position);

        if (viewPortPoint.x > 0.2f && viewPortPoint.x < 0.8f && viewPortPoint.y >
            0.2f && viewPortPoint.y < 0.8f)
        {
            if (alphaVar < 1)
            {
                alphaVar += Time.deltaTime / fadingDuration;
            }
        }
        else
        {
            if (alphaVar > 0)
            {
                alphaVar -= Time.deltaTime / fadingDuration;
            }
```

```
        }

        alphaVar = Mathf.Clamp01(alphaVar);
        mainCanvasGroup.alpha = alphaVar;
    }
}
```

```csharp
using UnityEngine;
using UnityEngine.SceneManagement;
using UnityEngine.UI;

public class PopUpMenuButton : MonoBehaviour
{
    [SerializeField] Image imageFade;
    Image panelImage;
    Color colorGreen;
    Color colorWhiteTransparent;
    float timeFading = 1.5f;

    private void Start()
    {
        panelImage = GetComponent<Image>();
        colorGreen = new Color(0, 255, 0, 1);
        colorWhiteTransparent = new Color(255, 255, 255, 0.588f);
    }

    public void ButtonSelected()
    {
        panelImage.color = colorGreen;
        StartSelectionSequence();
    }

    public void ButtonNotSelected()
    {
        panelImage.color = colorWhiteTransparent;
    }

    private void StartSelectionSequence()
    {
        Fade();

        switch (gameObject.tag)
        {
            case "Retry":
                Invoke("RetryLevel", timeFading);
                break;
            case "MainMenu":
                Invoke("LoadMainMenu", timeFading);
                break;
            case "Exit":
                Invoke("ExitApp", timeFading);
                break;
            default:
                break;
        }
    }

    private void Fade()
    {
        imageFade.canvasRenderer.SetAlpha(0.0f);
        imageFade.enabled = true;
        imageFade.CrossFadeAlpha(1f, timeFading, false);
    }

    private void RetryLevel()
    {
```

```csharp
        SceneManager.LoadScene(SceneManager.GetActiveScene().buildIndex);
    }

    private void LoadMainMenu()
    {
        SceneManager.LoadScene(0);
    }

    private void ExitApp()
    {
        print("Quit");
        Application.Quit();
    }
}
```

```csharp
using UnityEngine;

public class ButtonAndLineController : MonoBehaviour
{
    [SerializeField] GameObject targetObject;
    [SerializeField] Material whiteUnlitMaterial;

    LineRenderer lineRenderer;
    Vector3 offsetVector;
    float lineWidth = 0.015f;
    float t1 = 9.5f;
    float t2 = 15f;
    float t3 = 20.5f;
    float t4 = 27.5f;
    float t5 = 33f;
    float t6 = 37.5f;
    float t7 = 42.5f;

    // Start is called before the first frame update
    void Start()
    {
        gameObject.SetActive(false);
        lineRenderer = GetComponent<LineRenderer>();
        lineRenderer.enabled = false;
        lineRenderer.material = whiteUnlitMaterial;
        offsetVector = new Vector3(0.21f, 0, 0);

        ControlDisplayTime();
    }

    private void ControlDisplayTime()
    {
        switch (gameObject.tag)
        {
            case "Axis1":
                Invoke("DisplayAxisSignAndLine", t1);
                Invoke("HideAxisSignAndLine", t2);
                break;
            case "Axis2":
                Invoke("DisplayAxisSignAndLine", t2);
                Invoke("HideAxisSignAndLine", t3);
                break;
            case "Axis3":
                Invoke("DisplayAxisSignAndLine", t3);
                Invoke("HideAxisSignAndLine", t4);
                break;
            case "Axis4":
                Invoke("DisplayAxisSignAndLine", t4);
                Invoke("HideAxisSignAndLine", t5);
                break;
            case "Axis5":
                Invoke("DisplayAxisSignAndLine", t5);
                Invoke("HideAxisSignAndLine", t6);
                break;
            case "Axis6":
                Invoke("DisplayAxisSignAndLine", t6);
                Invoke("HideAxisSignAndLine", t7);
                break;
            default:
                break;
```

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```csharp
        }
    }

    private void DisplayAxisSignAndLine()
    {
        //Enable AxisSign
        gameObject.SetActive(true);

        //Enable LineRenderer component
        lineRenderer.enabled = true;

        //Create Offset
        Vector3 initialPosition = new Vector3(gameObject.transform.position.x,
        gameObject.transform.position.y, gameObject.transform.position.z) +
        offsetVector;

        // Set positions
        Vector3[] positions = new Vector3[2];
        positions[0] = initialPosition;
        positions[1] = targetObject.transform.position;
        lineRenderer.positionCount = positions.Length;
        lineRenderer.SetPositions(positions);

        //Define line width
        lineRenderer.startWidth = lineWidth;
        lineRenderer.endWidth = lineWidth;
    }

    private void HideAxisSignAndLine()
    {
        //Disable AxisSign
        gameObject.SetActive(false);

        //Disable LineRenderer component
        lineRenderer.enabled = false;
    }
}
```

```csharp
using UnityEngine;

public class RobotContoller : MonoBehaviour
{
    [SerializeField] Transform Axis1_Base;
    [SerializeField] Transform Axis2_Arm_01;
    [SerializeField] Transform Axis3_Arm_02;
    [SerializeField] Transform Axis4_Arm_03;
    [SerializeField] Transform Axis5_Arm_04;
    [SerializeField] Transform Controller_Claw_Snapping_Tool;
    [SerializeField] Transform Controller_Arc_Welder;
    [SerializeField] Transform ClawLeftController;
    [SerializeField] Transform ControllerLeftPincer;
    [SerializeField] Transform ClawRightController;
    [SerializeField] Transform ControllerRightPincer;

    float axisNumber = 0f;
    float rotationSpeed = 0f;
    float initialRotationInZ = 0f;

    private void Awake()
    {
        initialRotationInZ = ClawLeftController.transform.rotation.z;
    }

    // Update is called once per frame
    void Update()
    {
        PerformRotation(axisNumber);
    }

    public void PerformRotation(float selectedAxisNumber)
    {
        axisNumber = selectedAxisNumber;
        float rotationThisFrame = rotationSpeed * Time.deltaTime;

        switch (selectedAxisNumber)
        {
            case 1:
                Axis1_Base.Rotate(Vector3.forward * rotationThisFrame);
                break;

            case 2:
                Axis2_Arm_01.Rotate(-Vector3.forward * rotationThisFrame);
                break;

            case 3:
                Axis3_Arm_02.Rotate(-Vector3.forward * rotationThisFrame);
                break;

            case 4:
                Axis4_Arm_03.Rotate(Vector3.left * rotationThisFrame);
                break;

            case 5:
                Axis5_Arm_04.Rotate(Vector3.up * rotationThisFrame);
                break;

            case 6:
```

```
                    Controller_Claw_Snapping_Tool.Rotate(-Vector3.forward *
                     rotationThisFrame);
                    Controller_Arc_Welder.Rotate(-Vector3.forward * rotationThisFrame);
                    break;

            case 7:
                    ClawLeftController.Rotate(Vector3.forward * rotationThisFrame);
                    ControllerLeftPincer.Rotate(-Vector3.forward * rotationThisFrame);
                    ClawRightController.Rotate(-Vector3.forward * rotationThisFrame);
                    ControllerRightPincer.Rotate(Vector3.forward * rotationThisFrame);
                    break;
        }
    }

    public void AdjustSpeed(float newSpeed)
    {
        rotationSpeed = newSpeed;
    }
}
```

```csharp
using UnityEngine;

public class Laser : MonoBehaviour
{
    float laserDistance = 1000f;
    float lineWidth = 0.01f;
    LineRenderer lineRenderer;
    Material lineMaterial;

    // Start is called before the first frame update
    void Start()
    {
        lineRenderer = GetComponent<LineRenderer>();
        lineRenderer.enabled = true;
        AssignMaterialAndColor();
    }

    // Update is called once per frame
    void Update()
    {
        ThrowLaser();
    }

    private void ThrowLaser()
    {
        Vector3[] positions = new Vector3[2];

        // Check for collisions of the ray with objects that have colliders
        RaycastHit hit;

        if (Physics.Raycast(gameObject.transform.position, -
            gameObject.transform.forward * laserDistance, out hit, Mathf.Infinity))
        {
            //Draw Ray
            Debug.DrawRay(gameObject.transform.position, -
            gameObject.transform.forward * hit.distance, Color.blue);

            // Throw Ray from origin to the Raycast hit point
            positions[0] = gameObject.transform.position;
            positions[1] = hit.point;
        }
        else
        {
            // Throw Ray from origin to end default positions
            positions[0] = gameObject.transform.position;
            positions[1] = -gameObject.transform.forward * laserDistance;
        }

        // Set the positions
        lineRenderer.positionCount = positions.Length;
        lineRenderer.SetPositions(positions);

        //Define laser width
        lineRenderer.startWidth = lineWidth;
    }

    private void AssignMaterialAndColor()
    {
        //Create desired material and assign color
```

```
        lineMaterial = new Material(Shader.Find("Unlit/Color"));
        lineMaterial.color = Color.red;

        // Assign the material to the LineRenderer
        lineRenderer.material = lineMaterial;
    }
}
```

```csharp
using UnityEngine;

public class ConveyorBelt : MonoBehaviour
{
    [SerializeField] Transform endPoint;
    [SerializeField] float conveyorSpeed = 0.5f;

    private void OnTriggerStay(Collider other)
    {
        other.transform.position = Vector3.MoveTowards(other.transform.position,
        endPoint.position, conveyorSpeed * Time.deltaTime);
    }
}
```

```csharp
using UnityEngine;
using UnityEngine.SceneManagement;

public class ObjectToPick : MonoBehaviour
{
    AudioSource audioSource;

    [SerializeField] GameObject panelSuccess;
    [SerializeField] AudioClip successSound;
    [SerializeField] GameObject selectionObjects;
    [SerializeField] GameObject endLevelMenu;

    float zDistance = 2.75f;
    bool enableSuccessMessage = false;

    private void Start()
    {
        panelSuccess.SetActive(false);
        audioSource = GetComponent<AudioSource>();
    }

    private void Update()
    {
        UpdateSuccessMessagePosition();
    }

    private void UpdateSuccessMessagePosition()
    {
        if (enableSuccessMessage)
        {
            panelSuccess.transform.position = Camera.main.ScreenToWorldPoint(new
            Vector3(Screen.width / 2, Screen.height / 2, zDistance));
        }
    }

    private void OnCollisionEnter(Collision collision)
    {
        if (collision.gameObject.tag == "Belt")
        {
            StartSucessSequence();
        }
        else if (collision.gameObject.tag == "NoInteraction")
        {
            return;
        }
        else
        {
            SceneManager.LoadScene(SceneManager.GetActiveScene().buildIndex);
        }
    }

    private void StartSucessSequence()
    {
        Invoke("ShowSuccessMessage", 1.5f);
        Invoke("DisplayEndLevelMenu", 4f);
    }

    private void ShowSuccessMessage()
    {
```

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```csharp
        audioSource.PlayOneShot(successSound);
        enableSuccessMessage = true;
        panelSuccess.SetActive(true);
        selectionObjects.SetActive(false);
    }

    private void DisplayEndLevelMenu()
    {
        panelSuccess.SetActive(false);
        endLevelMenu.SetActive(true);
    }
}
```

```csharp
using UnityEngine;
using UnityEngine.UI;

public class SliderController : MonoBehaviour
{
    Slider mySlider;

    float x1 = -0.70426f;
    float x2 = -0.04669f;
    float y1, y2, m = 0f;

    // Start is called before the first frame update
    void Start()
    {
        mySlider = gameObject.GetComponent<Slider>();
        y1 = mySlider.minValue;
        y2 = mySlider.maxValue;
    }

    // Update is called once per frame
    void Update()
    {
        CollideRaycastWithSlider();
    }

    public void CollideRaycastWithSlider()
    {
        RaycastHit hit;
        //check for collisions of the ray with objects that have colliders
        if (Physics.Raycast(Camera.main.transform.position,
        Camera.main.transform.forward, out hit, Mathf.Infinity))
        {
            //Draw Ray
            Debug.DrawRay(Camera.main.transform.position,
             Camera.main.transform.forward * hit.distance, Color.yellow);

            //store collided object names
            var objectHitName = hit.transform.name;

            //find Slider object by name
            if (objectHitName == "Slider")
            {
                ChangeSliderValue(hit);
            }
            else
            {
                ResetSliderValueToZero();
            }
        }
    }

    public void ChangeSliderValue(RaycastHit hit)
    {
        Linearize(hit);
        mySlider.value = y2;
    }

    public void Linearize(RaycastHit hit)
    {
```

```
            print(hit.point.ToString("F5"));
            m = (x2 - x1) / (y2 - y1);
            x2 = hit.point.x;
            y2 = ((x2 - x1) / m) + y1;
        }

    public void ResetSliderValueToZero()
    {
        mySlider.value = 0f;
    }
}
```

```csharp
using UnityEngine;
using UnityEngine.UI;

public class AxisButtonController : MonoBehaviour
{
    Image panelImage;
    LineRenderer lineRenderer;
    AxisLine axisLine;

    private void Start()
    {
        panelImage = GetComponent<Image>();
        lineRenderer = GetComponent<LineRenderer>();
        axisLine = GetComponent<AxisLine>();
    }

    public void AxisSelected()
    {
        panelImage.color = new Color(0, 255, 0, 1);

        // Enable LineRenderer component attached to the gameObject
        lineRenderer.enabled = true;
    }

    public void AxisNotSelected()
    {
        panelImage.color = new Color(255, 255, 255, 0.588f);

        // Disable LineRenderer component attached to the gameObject
        lineRenderer.enabled = false;

        //Set to false the bool variable for the green color of the line in the
        AxisLine class
        axisLine.lineIsGreen = false;
    }
}
```

```csharp
using UnityEngine;

public class AxisLine : MonoBehaviour
{
    [SerializeField] GameObject targetObject;
    [SerializeField] Material whiteUnlitMaterial;
    [SerializeField] Material greenUnlitMaterial;

    LineRenderer lineRenderer;
    float lineWidth = 0.01f;
    public bool lineIsGreen = false;
    Vector3 offsetVector;

    // Start is called before the first frame update
    void Start()
    {
        lineRenderer = GetComponent<LineRenderer>();
        lineRenderer.enabled = false;
        offsetVector = new Vector3(0.21f, 0, 0);
    }

    public void EnableWhiteLine()
    {
        if (!lineIsGreen)
        {
            //Enable LineRenderer component
            lineRenderer.enabled = true;

            //Draw the line
            ThrowLine();

            //AssignWhiteColor
            MakeLineWhite();

            //Notify to DisableLine() that line is not green
            lineIsGreen = false;
        }
    }

    public void EnableGreenLine()
    {
        //Enable LineRenderer component
        lineRenderer.enabled = true;

        //Draw the line
        ThrowLine();

        //Assign White Color
        MakeLineGreen();

        // Notify to DisableLine() that line is green now
        lineIsGreen = true;
    }

    private void ThrowLine()
    {
        //Enable LineRenderer component
        lineRenderer.enabled = true;
```

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```csharp
        //Create Offset
        Vector3 initialPosition = new Vector3(gameObject.transform.position.x,
        gameObject.transform.position.y, gameObject.transform.position.z) +
        offsetVector;

        // Set positions
        Vector3[] positions = new Vector3[2];
        positions[0] = initialPosition;
        positions[1] = targetObject.transform.position;
        lineRenderer.positionCount = positions.Length;
        lineRenderer.SetPositions(positions);

        //Define line width
        lineRenderer.startWidth = lineWidth;
        lineRenderer.endWidth = lineWidth;
    }

    private void MakeLineWhite()
    {
        // Assign the material to the LineRenderer
        lineRenderer.material = whiteUnlitMaterial;
    }

    private void MakeLineGreen()
    {
        // Assign the material to the LineRenderer
        lineRenderer.material = greenUnlitMaterial;
    }

    public void DisableLine()
    {
        if(!lineIsGreen)
        {
            // Disable LineRenderer component
            lineRenderer.enabled = false;
        }
    }
}
```

```csharp
using UnityEngine;
using UnityEngine.UI;
using TMPro;

public class SelectionButtonController : MonoBehaviour
{
    [SerializeField] GameObject selectedObject;
    [SerializeField] GameObject dialogBoxPanel;
    [SerializeField] TextMeshProUGUI textDialogBox;

    Image panelImage;
    Image dialogBoxPanelImage;
    RaycastHit hit;

    Vector3 sizeLargeFrame = new Vector3(0.85f, 0.85f, 0.85f);
    Vector3 sizeSmallFrame = new Vector3(0.358f, 0.358f, 0.358f);

    Vector3 sizeLargeClaw = new Vector3(3.5f, 3.5f, 3.5f);
    Vector3 sizeSmallClaw = new Vector3(2.06f, 2.06f, 2.06f);

    Vector3 sizeLargeVacuum = new Vector3(2.5f, 2.5f, 2.5f);
    Vector3 sizeSmallVacuum = new Vector3(1f, 1f, 1f);

    Color colorWhiteTransparent;
    Color colorWhiteFull;
    Vector3 initialObjectPosition;
    float timeToInform = 0.01f;
    float fontSize = 0.25f;
    bool raycastCollision = false;
    bool objectSelected = false;
    bool objectCanBeUnselected = false;
    string unselectingText = "Unselecting tool...";

    private void Start()
    {
        panelImage = GetComponent<Image>();
        dialogBoxPanelImage = dialogBoxPanel.GetComponent<Image>();
        dialogBoxPanel.SetActive(false);
        initialObjectPosition = selectedObject.transform.position;
        colorWhiteTransparent = new Color(255, 255, 255, 0.588f);
        colorWhiteFull = new Color(255, 255, 255, 1f);
    }
    private void Update()
    {
        CheckRayCastCollisions();
        UpdateObjectPosition(hit);
    }

    public void ButtonSelected()
    {
        if (!objectCanBeUnselected)
        {
            objectSelected = true;
            SetLargeObjectSize();
            panelImage.color = colorWhiteTransparent;
            Invoke("InformObjectCanBeUnselected", timeToInform);
        }
    }
```

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```csharp
private void SetLargeObjectSize()
{
    switch (selectedObject.tag)
    {
        case "MetalFrame":
            selectedObject.transform.localScale = sizeLargeFrame;
            break;
        case "Claw":
            selectedObject.transform.localScale = sizeLargeClaw;
            break;
        case "Vacuum":
            selectedObject.transform.localScale = sizeLargeVacuum;
            break;
        default:
            break;
    }
}

private void InformObjectCanBeUnselected()
{
    objectCanBeUnselected = true;
}

public void UndoSelection()
{
    if (objectCanBeUnselected)
    {
        SetInitialObjectPositionAndSize();
        panelImage.color = colorWhiteTransparent;
        HideDialogBox();
    }
}

public void SetInitialObjectPositionAndSize()
{
    objectSelected = false;
    objectCanBeUnselected = false;
    selectedObject.transform.position = initialObjectPosition;
    SetSmallObjectSize();
}

private void SetSmallObjectSize()
{
    switch (selectedObject.tag)
    {
        case "MetalFrame":
            selectedObject.transform.localScale = sizeSmallFrame;
            break;
        case "Claw":
            selectedObject.transform.localScale = sizeSmallClaw;
            break;
        case "Vacuum":
            selectedObject.transform.localScale = sizeSmallVacuum;
            break;
        default:
            break;
    }
}

private void CheckRayCastCollisions()
{
```

```csharp
        if (Physics.Raycast(Camera.main.transform.position,
          Camera.main.transform.forward, out hit, Mathf.Infinity))
        {
            //Draw Ray
            Debug.DrawRay(Camera.main.transform.position,
             Camera.main.transform.forward * hit.distance, Color.blue);
            raycastCollision = true;
        }
        else
        {
            raycastCollision = false;
            SetInitialObjectPositionAndSize();
        }
    }

    private void UpdateObjectPosition(RaycastHit hit)
    {
        if (raycastCollision && objectSelected)
        {
            selectedObject.transform.position = hit.point;
        }
    }

    public void ButtonNotSelected()
    {
        SetInitialObjectPositionAndSize();
        panelImage.color = colorWhiteTransparent;
    }

    public void ShowUnselectingDialogBox()
    {
        if (objectCanBeUnselected)
        {
            dialogBoxPanel.SetActive(true);
            dialogBoxPanelImage.color = colorWhiteFull;
            textDialogBox.fontSize = fontSize;
            textDialogBox.text = unselectingText;
        }
    }

    public void HideDialogBox()
    {
        dialogBoxPanel.SetActive(false);
    }
}
```

```csharp
using UnityEngine;
using System.Collections;
using TMPro;
using UnityEngine.UI;

public class ToolController : MonoBehaviour
{
    [SerializeField] Material materialOriginal;
    [SerializeField] Material materialGreen;
    [SerializeField] GameObject dialogBoxPanel;
    [SerializeField] TextMeshProUGUI textDialogBox;
    [SerializeField] Image imageTimer;
    [SerializeField] GameObject selectionObjects;
    [SerializeField] Animator robotAnimator;
    [SerializeField] GameObject attachedRobotTool;
    [SerializeField] GameObject panelObject;
    [SerializeField] GameObject belt;
    [SerializeField] AudioClip successSound;
    [SerializeField] GameObject animAudioPlayer;
    [SerializeField] GameObject endLevelMenu;

    AudioSource audioSource;
    MeshRenderer toolMeshRenderer;
    Image dialogBoxPanelImage;
    Vector3 initialObjectPosition;

    bool timerIsEnabled = false;
    bool freezeDialogBox = false;
    string dockingText = "Attaching...";
    string successText = "Correct tool!";
    string failText = "Choose a tool again!";
    float fontSize = 0.25f;
    float currentTime = 0f;
    float totalTime = 3f;
    float waitingTime = 2f;

    // Start is called before the first frame update
    void Start()
    {
        audioSource = GetComponent<AudioSource>();
        toolMeshRenderer = GetComponent<MeshRenderer>();
        dialogBoxPanelImage = dialogBoxPanel.GetComponent<Image>();
        dialogBoxPanel.SetActive(false);
        animAudioPlayer.SetActive(false);
    }

    // Update is called once per frame
    void Update()
    {
        TimerOn();
    }

    void OnCollisionEnter(Collision collision)
    {
        if (collision.gameObject.tag == "StaticRobotCollider")
        {
            StartDockingSequence();
        }
        else
```

```csharp
        {
            return;
        }
    }

    private void StartDockingSequence()
    {
        dialogBoxPanel.SetActive(true);
        dialogBoxPanelImage.color = new Color(250, 200, 0, 1f);
        textDialogBox.fontSize = fontSize;
        textDialogBox.text = dockingText;

        timerIsEnabled = true;
    }

    private void TimerOn()
    {
        if (timerIsEnabled)
        {
            currentTime += Time.deltaTime;
            imageTimer.fillAmount = currentTime / totalTime;

            if (currentTime >= totalTime)
            {
                TimerOff();
                if (gameObject.tag == "MetalFrame")
                {
                    StartSucessSequence();
                }
                else
                {
                    StartFailSequence();
                }
            }
        }
    }

    private void StartSucessSequence()
    {
        toolMeshRenderer.material = materialGreen;
        dialogBoxPanelImage.color = new Color(0, 255, 0, 1f);
        textDialogBox.text = successText;
        audioSource.PlayOneShot(successSound);

        freezeDialogBox = true;

        Invoke("SelectionObjectsOff", 2f);
        Invoke("AnimateRobot", 2.1f);
        Invoke("TurnOnConveyorBelt", 20f);
        Invoke("DisplayEndLevelMenu", 34.5f);
    }

    private void StartFailSequence()
    {
        dialogBoxPanelImage.color = new Color(255, 0, 0, 1f);
        textDialogBox.text = failText;
        freezeDialogBox = true;

        panelObject.GetComponent<SelectionButtonController>().SetInitialObjectPosit
        ionAndSize();
    }
```

```csharp
    private void SelectionObjectsOff()
    {
        selectionObjects.SetActive(false);
    }

    private void AnimateRobot()
    {
        attachedRobotTool.SetActive(true);
        robotAnimator.enabled = true;
        animAudioPlayer.SetActive(true);
    }

    private void TurnOnConveyorBelt()
    {
        belt.SetActive(true);
    }

    private void DisplayEndLevelMenu()
    {
        endLevelMenu.SetActive(true);
    }

    private void TimerOff()
    {
        timerIsEnabled = false;
        imageTimer.fillAmount = 0f;
        currentTime = 0f;
    }

    void OnCollisionExit(Collision collision)
    {
        if (freezeDialogBox)
        {
            StartCoroutine(WaitAndApplyOnCollisionExitSettings());
        }
        else
        {
            ApplyOnCollisionExitSettings();
        }
    }

    void ApplyOnCollisionExitSettings()
    {
        toolMeshRenderer.material = materialOriginal;
        dialogBoxPanel.SetActive(false);
        freezeDialogBox = false;
        TimerOff();
    }

    IEnumerator WaitAndApplyOnCollisionExitSettings()
    {
        yield return new WaitForSeconds(waitingTime);
        toolMeshRenderer.material = materialOriginal;
        dialogBoxPanel.SetActive(false);
        freezeDialogBox = false;
        TimerOff();
    }
}
```

```csharp
using UnityEngine;

public class DialogBoxController : MonoBehaviour
{
    RaycastHit hit;
    Vector3 offsetVector = new Vector3(0f, 1.3f, 0.2f);

    // Update is called once per frame
    void Update()
    {
        AssignObjectPosition();
    }

    private void AssignObjectPosition()
    {
        if (Physics.Raycast(Camera.main.transform.position,
        Camera.main.transform.forward, out hit, Mathf.Infinity))
        {
            gameObject.transform.position = hit.point - offsetVector;
        }
    }
}
```