JANUS

Practical handbook for teachers with guidelines on how to integrate Virtual Reality for Robotics education

Co-funded by the Erasmus+ Programme of the European Union

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Cite as: *Antonelli et al., (2023) Practical handbook for teachers with guidelines on how to integrate Virtual Reality for Robotics education. JANUS: e-Pedagogy and Virtual Reality Based Robotic Blended Education. Project No 2020-1-PL01-KA226-HE-095371. Available on:* *https://janus.w.prz.edu.pl/project-results*

Statement of originality

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Note

For anyone interested in having more information about the project, please see the website at: www.janus-project.eu

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Definitions and abbreviations

AT - Assessment Tasks

BE - Blended Education

BL – Blended Learning

GUI – Graphical User Interface

ILO - Intended Learning Outcome

LMS – Learning Management System

STEM – Science, Technology, Engineering, Mathematics

TLA – Teaching and Learning Activities

VR – Virtual Reality

VR – Virtual Reality

VRT - Virtual Reality Tool

Introduction

Virtual reality (VR) in robotics education refers to technologies that enrich the knowledge and experience of students, mainly in the context of digital robot twins. Robotics is a multidisciplinary field of knowledge that deals with the design, construction, but also operations, use, and maintenance of robots.

In recent years, VR technologies have evolved creating several possible scenarios for their use. One of them is the creation of immersive educational experiences that allow students to learn in a safe and controlled environment. VR technology can simulate real-world scenarios and provide students with hands-on experience operating robots, without the need for expensive physical equipment. This can make robotics education more accessible and cost-effective, and also allows for a higher degree of flexibility in the curriculum.

VR can support teachers in educating students in the traditional way, that is, providing students with visual cues so that they understand complex robot concepts and mechanics. Another approach to VR robotics education is to create a digital twin and teach students, for example, how to work with a robot, taking into account all safety rules.

A concept that has gained importance in the field of education in recent years is blended learning (BL). This way of teaching has gained particular importance during the COVID-19 pandemic. Blended learning is an approach to education that combines traditional face-to-face instruction with online learning. This approach aims to take advantage of the benefits of both in-person and online learning, and to provide a more flexible and personalized learning experience for students. Blended learning allows for more active collaborative learning; e.g., students taking a course using this type of learning can participate in project work online, but also combine this with actual discussions in actual labs. The existence of such a choice for types of class creates an environment that can encourage more active learning.

The JANUS project aims at setting up the foundations related to the application of Virtual Reality (VR), in blended learning settings, with particular focus on the field of STEM (Science, Technology, Engineering, and Mathematics) education. Project-related activities can be broadly classified into the following categories:

(1) e-Pedagogy: Development of an educational framework to support the design of VR learning activities and a user manual to guide the practices that educators will follow when conducting the educational activities. Furthermore, prior to the intervention, a series of workshops were delivered to prospective teachers so as to equip them with the necessary skills and traits on how to use the custom-made prototype efficiently and effectively.

(2) Virtual learning platform: Aligned to the principles of well-established educational theories and instructional design techniques, a prototype VR platform was developed. The VR-based solution feature a safe environment in which students are able to interact with the learning content and perform various subject-specific tasks.

(3) Learning Analytics: By integrating a universal system, such as ViLLE, the future development decisions of the instructional designers (e.g., intervention design, content creation) are data-driven and context-specific while the educational practices of the teachers (i.e., didactic approach, instructional methods) can be optimised in accordance with the needs. Moreover, by offering learners insights about their learning progression and hints on how to improve their learning practices, the overall educational experience becomes more efficient and effective.

About this Handbook

The Janus project is one of the innovative ideas for educating students in robotics topics. This project includes the development of tools and methodologies needed to offer teacher support for virtual reality teaching for certain aspects of robotics. The approach can be used as a fully virtual, but more importantly it can be offered as blended learning.

The purpose of this Handbook is to offer guidelines for integrating virtual reality into robotics education. Two practical case studies were used to demonstrate the implementation of this goal. One was the implementation of virtual reality in robotics education for a collaborative robot at the Politechnico di Torino in Italy, while the other case study is about an ABB robotic arm and the process of machining, among other things, a car rim at the Rzeszów University of Technology in Poland.

This hanbook is divided into 4 main sections:

- Virtual reality background for robotic education - this is an introduction to the subject of virtual reality, this chapter presents the basic definitions related to the subject and describes the essence of the use of VR in the education process, it also shows cases of using VR in the field of robotics education.

- Virtual reality for Robotic education - case study integration - this chapter describes the exemplary integration of the developed robotics scenarios for the education of students for two courses that are the subject of the JANUS project, it describes the process of creating such educational scenarios,

- Evaluation of the students' performance platform - this is a description of the process of evaluating students, which includes a description of sample scenarios that are implemented before, during and after the course,

- Example of the intervention plan for teachers - this is a chapter that presents an example of a teacher intervention plan that sends current information to implement the developed robotics course.

In addition, readers have a possibility to get more information on the process of creating and testing the developed solutions described in detail in the appendices to the handbook, namely:

- Theoretical and Conceptual Framework for applying virtual reality into educational process (**Annex 1**),
- Examples of Intended Learning Outcomes (ILO), Teaching and Learning Activities (TLA) and Assessment Tasks (AT) for case study applications (**Annex 2**),
- Process of development of the VR platform and Educational Scenario (3D Content) (**Annex 3**),
- Pilot of the use case with Case Studies Monitoring and Continues Data collections from use cases (**Annex 4**),
- Presentation of ViLLE – The Collaborative Education Tool in a form of Teacher Guide (**Annex 5**),
- Backend API & Server Configuration for linking virtual reality with learning analytics (**Annex 6**),
- Description of the Unit Testing process (**Annex 7**),
- Specification of the research plan and the data collection instruments (**Annex 8**),
- Analysis of the primary data and visualisation of the outcomes (**Annex 9**),
- Framework for Virtual Reality Platform (**Annex 10**),
- Integration of Assessment as Teaching-learning Tool (**Annex 11**),
- Presentation of Training Sessions delivered for teachers (**Annex 12**).

1. Virtual reality background for robotic education

1.1. The importance of virtual reality

Q. Zhang, Ke Wang, Sheng Zhou (2020) notice that virtual reality (VR) is a comprehensive integrated technology. The principle is to build a virtual three-dimensional space world through computing tools. When users wear special eyes, helmets, gloves and other devices, users can receive sensory simulations such as real vision, hearing and touch in the virtual world. The computer can track, calculate and send the corresponding changes of 3D scene in real time. With the user's real-time experience of interactive feeling, users can observe the whole 3D space at will. The technical fields mainly involve computer graphics, sensor technology, human-computer interaction technology, artificial intelligence and science and technology. The key to combine these technologies is advanced simulation system. In short, virtual reality is a new way of interaction between human and computer. Also Q. Zhang, Ke Wang, Sheng Zhou. (2020) highlight that virtual reality is a new way of human-computer interaction. In a virtual world, sensory patterns such as vision, hearing or touch can be realised, but require special tools such as special goggles, helmets (headmounted-displays), gloves or other devices. For example, high fidelity graphics and immersive content using headmounted-displays have enabled students to explore complex subjects and improve learning outcomes, as these virtual tools allow students to learn in their preferred learning style (J. Taljaard, 2016).

Virtual Reality (VR) is a multi-sensory technology that stimulates learning and has the potential for pedagogical applications (R. Pathan, R. Rajendran, S. Murthy (2020). These last thoughts already show that the inclusion of new technologies to education process such as VR facilitate students' learning, interaction, and satisfaction in environments. For the implementation of such kind new technologies it is important to think about instructional methods and in that case it can create a richer, more satisfying learning environment, that can improve learning performance of individuals with different cognitive styles (e.g., learning styles and spatial ability) (P. Safadel, D.White (2020). Also virtual environments and 3D objects can explain certain educational contents that text cannot, and those are unique benefits of VR applicable in education (M. Hussein, C. Nätterdal, 2015). Important to notice that T. J. Bastiaens, L. C. Wood, T. Reiners (2014). pointed out that VR software tools can be used to bring textbook content to life. Virtual reality promotes active learning and enables better concentration since students are focused on virtual environment with a strong sense of presence within (M. Hussein, C. Nätterdal, 2015). In the following discussion of the advantages of virtual reality, it is important to note that the authors emphasise short-term work in educational VR which positively affects the development of knowledge, thinking, and other cognitive processes. VR educational programs stimulate personal, procedural, and operational mechanisms of thinking, which result in the higher student performance. VR-programs improve traditional parameters of figurative short-term memory, observation, stability and attention span, and generalization and classification (V. V. Selivanov, L. N. Selivanova, N. S. Babieva, 2020). Also according to Q. Zhang, Ke Wang, Sheng Zhou. (2020) quality and ability of students have been greatly improved after virtual education platform learning. Also research suggests that simultaneous group VR experiences with multiple students stimulate students' sense of community and collaboration in contrast to parallel learning experiences (A. G. Fegely , H. N Hagan, G. H. Warriner, 2020). The significance of virtual technologies is that it helps users to have an active experience rather than a passive learning experience and enhances their creativity (M. Samad, E. Sepasgozar, 2020).

It is important to note that virtual reality is even seen as a way of education, with A.K. Bashabsheh, H. Alzoubi, M. Z. Ali (2019) argue that VR education can change the way educational content is delivered by creating a virtual world - real or imagined - and allowing users to not only see it but also interact with it. The interaction aspect is also highlighted by other researchers (N. Shamsudin, F. Abdul Majid, 2019), who point out that the interaction of the learner with the content is crucial in virtual spaces. This suggests that the learning content that fills and makes sense of the virtual space is crucial. This suggests that it is not only important to attract interest in the possibility of learning in a virtual space, but it is also important to create an active learner position where the student is involved in the learning content. As mentioned N. Shamsudin, F. Abdul Majid (2019), VR is a new technology that provides interaction with learning content. This interaction will potentially deepen the learning effect when the learners are actively constructing new knowledge through virtual environments. Virtual reality causes the learner to cognitively process the learning material more deeply; learners can acquire knowledge and skills effectively. The ability to provide highly interactive learning experiences is one of the best-valued in virtual reality (N. Shamsudin, F. Abdul Majid, 2019). N. Shamsudin, F. Abdul Majid (2019) study suggests that virtual reality can effectively engage students in a learning activity, as demonstrated by heightening levels of engagement through interaction, and immersion VR features and that this may be activated by increasing levels of interactions (N. Shamsudin, F. Abdul Majid (2019). Also having virtual reality in education is useful not only for content consumption, but it’s also great for content creation. Also virtual reality inspire student‘s creativity. Education (e.g. high turnover rate of knowledge, changing labour market), which require a more creative response of learners to the world problems that surround them. J. Bidarra, E. Rusman (2017). A. K. Bashabsheh, H. Alzoubi, M. Z. Ali (2019) mention that the use of VR technology is an essential tool to transfer from teacher – centered methodology to student- centered methodology of learning.Students are interested in moving from the traditional way of teaching to other and more efficient teaching methods and using many tools. It has been proved that VR technology is a good tool for this movement.The traditional way of teaching lacks of enjoyment and VR technology is a good solution to increase the enjoyment of learning (A. K. Bashabsheh, H. Alzoubi, M. Z. Ali (2019). VR technology is a good solution to enhance enjoyment. As A. K. Bashabsheh, H. Alzoubi, M. Z. Ali (2019), virtual reality has the potential to change the way educational content is delivered; virtual reality is based on the premise of creating a virtual world, real or imaginary, that learners can not only see but interact with. N.

Shakirova, N.Al Said, S. Konyushenko (2020) research show that VR technology implementation allowed a better understanding of the complex concepts and contributed to gaining experience in the chosen professional field. Modern digital technologies based on VR can create the foundation for effective and high-quality training with an orientation on practice and productivity.

Also the academic literature also highlights the important educational aspects that need to be maintained in the virtual space.For example, the flexibility, repeatability, and visual appeal of a virtual platform could promote the development of students' abilities in active learning, reflective thinking, and creativity.

1.2. The main groups of virtual reality

Virtual reality systems into two main categories: (a) fully immersive virtual environments (*Immersive Virtual)* and partially immersive virtual environments, where the learner observes or interacts with everything on the screen *(Non immersive).* Immersive systems totally surround the users, they do this through specific hardware and need high-end computing power. Immersive virtual reality systems is replaced with head mounted display unit. Non-immersive systems - the viewers supposedly are not totally immersed using more generic hardware. It is as window-on-a-world systems in which the virtual reality can be seen through display screen (A. K. Bashabsheh, H. Alzoubi, M. Z. Ali, 2019). Other authors (R. Nakatsu, N. Tosam, 2005) immersion see as passive immersion and active immersion. The lack or the existence of interaction is the key element that distinguishes these two types of immersion. Active immersion is important for virtual reality, includes interacting with objects, whereas in passive immersion the users only receive information with no interaction. A virtual reality experience should involve an active immersion. According to Q. Zhang, Ke Wang, Sheng Zhou (2020) who speak about the different functions and implementation methods of virtual reality system, notice that it can be divided into three types (**Figure 1**) (Read more in **Annex 10**).

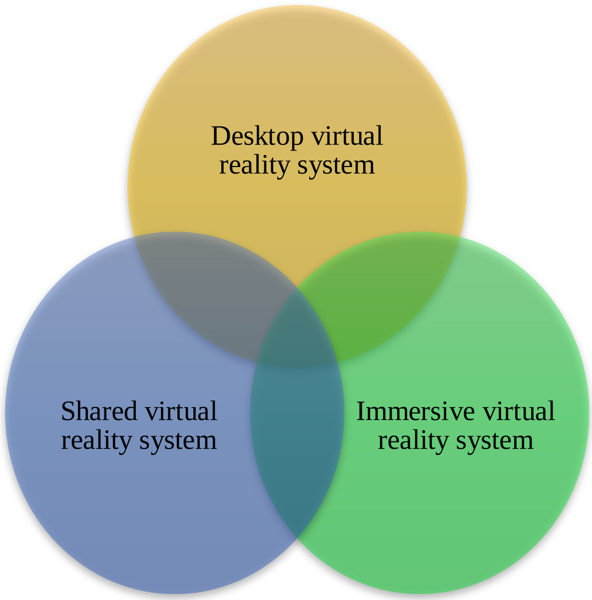

Figure 1 - Types of virtual reality systems

1.2.1. Desktop virtual reality system

Desktop virtual reality system is also known as simple virtual reality system, which makes computer monitor become a window for users to observe virtual scene and simulate it through computer and low-end workstation, thus allowing users to fully interact with virtual reality world through input devices. These input devices include stereo glasses, sensors, mouse, 3D controller, torque, etc. These types of systems allow users to freely select, observe and manipulate the virtual objects in the virtual scene, but they lack immersion because they are affected by external environment factors in the learning process. The application of this system in medical teaching is mainly reflected in the making of virtual courseware and virtual learning environment.

1.2.2. Immersive virtual reality system

Is known as "wearable" virtual reality systems, provide a much higher sense of immersive experience than desktop virtual reality systems. Some display devices are used to close the vision, hearing and touch of the participants to avoid the interference of external factors.

Trackers, data gloves and other hand-controlled input devices are used to immerse the participants, providing them with a completely virtual and closed new space. Speaking about immersive virtual reality, it is important to notice that fully immersive virtual reality systems provide the participant with three-dimensional virtual scenes in a large field of view. Field of view, or field of vision, refers to what a stable eye can see at a given moment (W. R. Sherman, A.B. Craig, 2003), measured in degrees. Understanding Virtual Reality: Interface, Application, and Design, First ed. Morgan Kaufmann Publishers. Immersive experiences, such as virtual reality (VR) and augmented reality (AR), have redefined how digital media can be delivered, encouraging us to interact with and explore our environment (L. E. Reevesa, E. Boltonb, M. Bulpitta, A. Scotta, I. Tomeyc, M. Gatesc, R. A. Baldockd, 2021).

1.2.3. Shared virtual reality system

Shared virtual reality system also known as network virtual reality systems or distributed virtual reality systems, are based on the network connection of immersive virtual reality systems and distributed interactive simulation. Through the Internet, multiple users can join a virtual scene or space, experience the scene of virtual reality together, and promote the virtual reality to a higher level. In a virtual scene, the same object or model can be manipulated and observed by different users to achieve the purpose of common learning and experience.

1.3. What can we teach in Virtual Reality in case of robotic education

Virtual Reality (VR) can be a powerful teaching tool for a variety of reasons. Foremost, when students participate in VR experiences that include real people and places it allows students to develop feelings of immersion and presence in the VR environment (M. Slater, 2018), which is an active learning and experiential learning upgrade over students reading textbooks or watching videos to learn about a topic. As introduced above, VR provides an avenue for a variety of different experiences that would not ordinarily be possible in the physical world. For example, with VR, students in history lessons can have experiences that place them in the time period being studied in order to enhance their understanding of the lesson topic, and thus aid understanding and transfer into long-term memory (J. R. Domingo, E. G. Bradley, 2018). Further, VR applications allow students to become immersed in experiences that develop their sense of empathy for the people and events depicted in the VR environments, like the reasons why historical figures made their decisions given the context of the historical events (A. van Loon, J. Bailenson, J. Zaki etc., 2018). It is a vital element for the virtual reality system to understand, or sense, the participant's interaction and thus provide the appropriate feedback. This should be done in a real-time manner (S. M. Preddy, R. E. Nance, 2002). Also VR experiences can mimic the social aspects of traditional experiential learning activities, as well. Virtual Reality may be useful for training the spatial orientation skill. The spatial orientation skill allows us to determine *our location in relation to the environment. In addition to map reading,* an activity that provides the spatial orientation skill is wayfinding. While wayfinding the information obtained from successive views of the environment provides spatial orientation. is displayed through a Smartphone installed in VR 3D glasses (C. Carbonell-Carrera, J. L. Saorin (2018). Also it is important to mention that in virtual reality students must learn of holistic environment empowerment.

V. Román-Ibáñez, Fr. A. Pujol-López, H. Mora-Mora (2018) notice that this is important that the robot is taught not only the functions of the robot, but also collision detection, an easy-to-use cell design interface or reachability path checks among others, as they are used to teach only fundamental concepts of robotics. It is necessary to use the virtual environment of the robot holistically, that environment must be educational. It must be possible for the learner to generate additional robot programs, when the student not only purposefully performs one activity, task, but is able to choose, test the possibilities of the robot and the virtual reality surrounding the robot. This will enable students to apply the skills they have developed in their professional activities. On this basis, an enabled virtual reality is created, and a comprehensive learner experience is formed (V. Román-Ibáñez, Fr. A. Pujol-López, H. Mora-Mora, 2018).

The concept of using digital twin in virtual reality has been around for some time. Digil twin is used to replicate a real environment, a process, or a single object that, for example, performs certain operations. In the described work, such an object could be a robot in a laboratory environment. Another example of the use of virtual reality is human-robot cooperation, which allows for primarily safe cooperation. Proper use of virtual reality for purposes such as education allows for comfortable and safe training of students in cooperation with the robot, as well as, for example, its programming. Another exemplary use of virtual reality in the field of robotics is for training purposes, for example, the behavior of personnel in the presence of a station with a robot. Virtual reality can also help, for example, increase efficiency and optimize the movement of the robot to increase productivity of, for example, a production line.

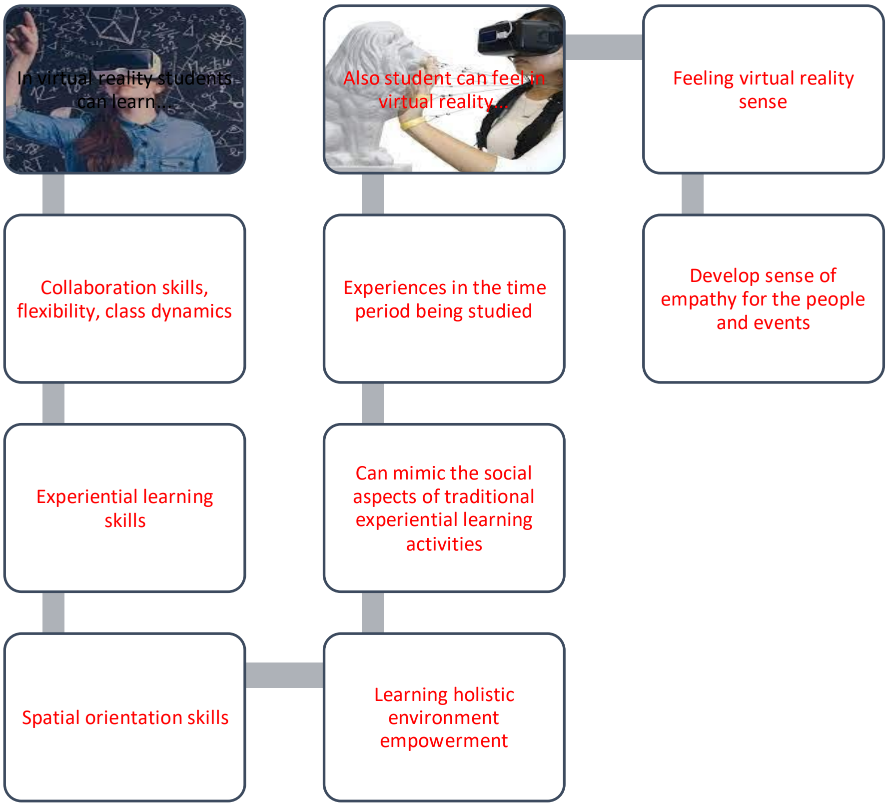

Figure 2 - The main aspects which learners can learn and feel in virtual reality

In **Figure 2** it is presented the main aspects which students can learn in virtual reality. Also learning process in virtual reality is directly oriented to learners feelings, emotional part, so it is important to pay attention to the feelings which learner can feel or develop in virtual reality. With virtual worlds, new educational practices are explored based on consolidated digital pedagogical models, or that are in the process of being so. This type of tool contributes its own in pedagogical and methodological terms, providing both teacher and student with an alternative way of teaching and learning, and at the same time complementary to learning models such as hybrid and mobile. In addition, it facilitates the teacher the use of pedagogies such as inverted class and collaborative learning, among others, there by promoting flexibility and class dynamics (Marín-Díaz et al. 2022). As A. G. Fegely , H. N. Hagan and G. H. Warriner (2020) point out, authentic experiential learning is disappearing from education, but it is likely that low-cost VR solutions will become a popular alternative, but it is important that VR is based on structure and direction. This type of VR can activate student learning.

1.4. Educational aspects of virtual reality

In the field of education, there is a lot of talk about active learning methods and the importance of their use in the educational process, as it is activities that engage students in the learning process, foster higher levels of thinking, creativity, initiative, the dissemination of effective ideas, and the full integration of teamwork (S. Freeman, S. L. Eddya, M. McDonough, et al, 2013). Currently learning is seen as an engaging process which provides experiences and allows learners to develop skills and competences of different cognitive, emotional and psycho-motor complexity (L. F. Dreimane, 2019). At the same time, researchers (C. L. Konopka, M. B. Adaime, P. H. Mosele, 2015) point out that active learning methods often become part of the routine, with lecturers selecting methods based on their modernity, or simply on their simple applicability, neglecting the relevance to the lesson's purpose or objectives. At the same time, it is stressed that the discourses of the traditional classroom, where the teacher dominates the educational process, continue to prevail at different levels of education. Therefore, this report, by exploring virtual reality and robotics, aims to reflect the principles of modern pedagogy, where it is important to involve the learner in the educational process. Educational activities for virtual reality are sumarized in **Figure 3**.

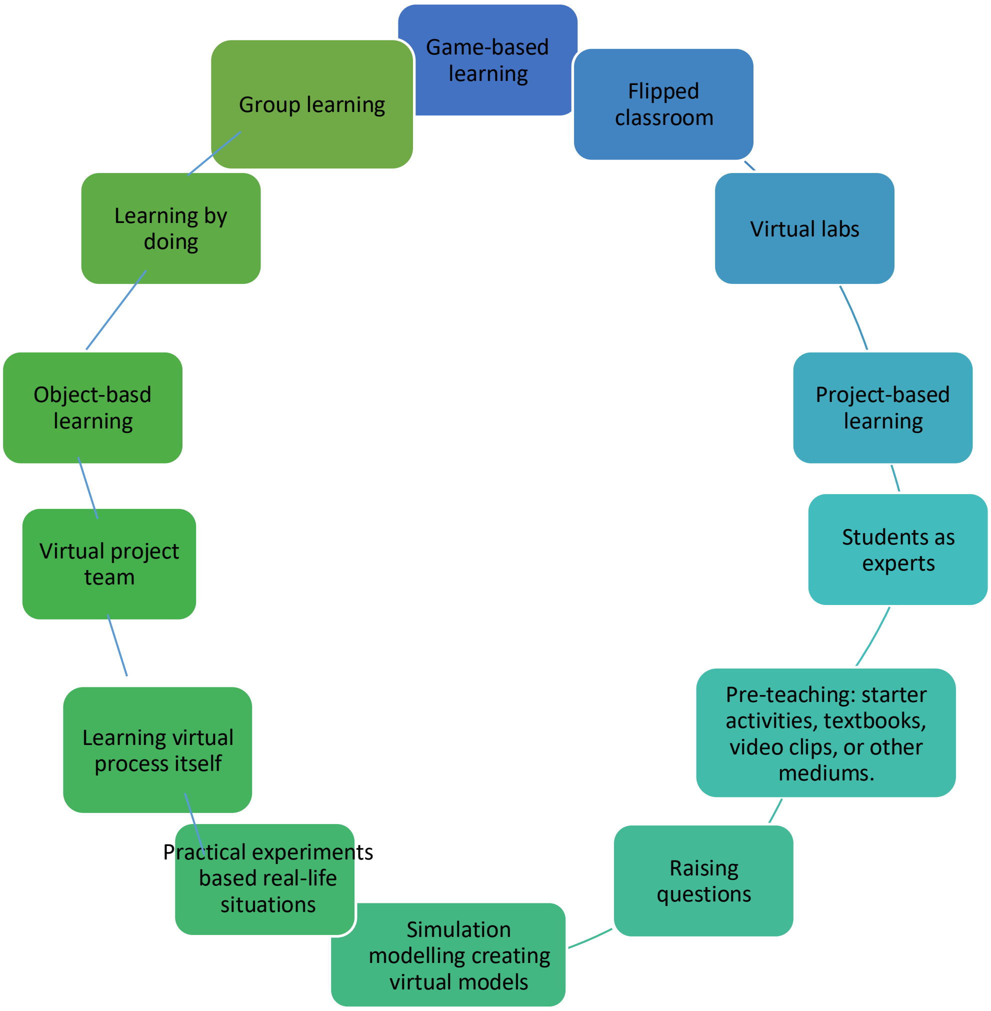

Figure 3 - Educational activities for virtual reality: looking for a successful way for e-pedagogy and blended learning

Speaking about learning with robots in virtual reality, it is important to speak about a variety of learning methods.

1. Developing active students' position, who are able individual to study learning material. This is the model when first students read, learn and then they came to learning community. A) First of all, it is important to mention **pre-teaching activities** when lecturer can use activities or use textbooks, video clips, or other mediums. Learning media in principle is a device used to convey learning material and provide convenience for students in achieving learning objectives. The learning process is regarded as successful if there is a change in student behavior. Thus, the learning media must provide facilities to move students from not knowing to knowing, from not understanding to understanding, from the easiest things to difficult things, from simple things to complex things. and from real things to abstract things. The more effective learning media, the more effective the learning process will be. (E. Marpanaji, et al., 2018). As mentioned A.G. Fegely et al. (2020), instructors will deliver pre-teaching to the whole class before entering the VR experience. Instructors can include engine starter activities or use textbooks, video clips, or other mediums to introduce lesson topics and build student back-ground knowledge. Teachers will share the compelling questions or students will create their own compelling questions in this step. The introduction part of lessons is also the ideal time for instructors to explain their expectations for behavior for the VR activities, how to use or navigate the VR experiences, and what students should be doing, like taking notes, as they embark on the VR experiences together (A.G. Fegely et al.,2020). In this context, it is also important to mention the quality of the presentation of the material offered to students. For example, requirements for media quality are stated. M. Samad, E. Sepasgozar (2020) notice that *media can consist of recorded video, audio. Also it can be combined with quizzes and interviews* (M. Samad, E. Sepasgozar, 2020). Also in media there is an opportunity for *motion tracking systems and stereo sound* in the VR environment which allowed students to interact with the projected modules allowing the opportunity for an immersive experience within an interactive VR environment. Also VR videos can be uploaded to a video delivery service that supports VR video, on YouTube. Students can view the VR video content through a desktop/mobile web browser, or through the Android/iOS YouTube apps (M. Samad, E. Sepasgozar, 2020). Media form can also be considered perceptual

immersion that surround the senses, to produce a sensorially rich mediated environment. These presented educational activities can be used when students need to familiarize themselves with the learning material, as well as to stimulate students' engagement through puzzles and interesting videos. Another important aspect is that preparing videos and placing them in the students' hands at any time and on any device promotes learning at their convenience. B) In further exploring educational activities aimed at actively engaging students in virtual environments, it is important to note that researchers have identified ***learning virtual process itself which*** shows that students can study topics related to virtual processes themselves. The main facts about learning virtual process itself: a) Students learn not only the theoretical methods, but also structure of technical systems and technological processes on the models; consequently they will be better prepared for practical professional work. b) student learns virtual process itself but does not description of the process. In addition, the student is exploring the virtual software environment in which this process can be improved. The use of such methods of learning allows you to increase the interest of students, and also to prepare them for professional career. In addition, detailed analysis of the processes and risks that may arise, will allow students to avoid injuries later. These activities allow students to delve into a topic before hand, even though it has not yet been covered in a lecture or tutorial.

C) As can be seen, the latter approaches particularly highlight the role of students as learners in virtual space. So ***students as Experts*** is other educational method which can be applied in virtual reality. Students may have more time and interest to dive deep into projects or technologies, quickly becoming experts relative to the educators supporting them. This is an amazing opportunity to build their confidence and identity as valued contributors within the institution (S. Silva, E. C. R. Marinho, etc., 2017). Individual students, classes, or clubs can identify compelling applications, models, and technologies, and introduce them to educators. They can also support educators directly by setting up stations, facilitating sessions, creating quick-start guides, and mapping out alignment between learning objectives and applications. Skill movement during students practice. Skill is a kind of movement system, which can perform some tasks acquired through practice. Skills can be divided into primary skills and technical skills according to their skill levels. Primary skills indicate unskilled, and the primary skills are purposeful, and through repeated practice to automate operations and achieve skill level. According to the different characteristics, it can be divided into writing, cycling and other motor functions and arithmetic, writing and other intellectual functions. In the process of forming skills, various skills and actions affect each other. It can be said that if skills promote the formation of new skills, it is called skill movement. If an established skill hinders the formation of a new skill, it is called a skill disturbance (Q. Zhang, Ke Wang, Sheng Zhou, 2020).

D) Another important educational method is ***Flipped Classroom*** when students first study a topic and then discuss it in lectures. This way of learning encourages students to think independently, promotes self-direct learning. This model of lectures or readings as homework and group work or hands-on activities in class is a great fit for immersive learning. It allows class time to focus on *collaborative, social activities like multiplayer games or project-based learning,* access to technology and space students may not have at home, and individual or small-group guidance from educators. The flipped classroom is a change in the sequence in which activities are done by which students interact with the course materials. In the flipped classroom, students preview the course materials before class so that they can do a part of their homework and other learning activities in class (workshop). Also lesson materials can be available to students before class, including digital content and short videos. Preparing students before class or supporting them after class one by one is not easily possible in large classes (M. Samad, E. Sepasgozar, 2020). T. Dombrowski, St. Dazert, St. Volkenstein (2019) notice that the flipped classroom and the virtual reality seem to have a particularly high potential. According to scientific literature, flipped classroom can be integrated in virtual reality.

1.4.1. Learning between others in synchronic/asynchronous collaboration

Group learning is important educational activity which can be applied in virtual reality. M. Samad, E. Sepasgozar (2020) notice that some of the most important knowledge we gain doesn't come from what we hear from lecturers, but rather from collegiality and debate. VR education gives the opportunity to make learning experiences social by allowing students to communicate with each other. Using avatars and mapped facial expressions, people can come together to discuss, synthesize, and learn from one another.

A) ***Group-based learning methods*** consist of: *problem-solving with open-ended solutions, hands-on projects, and team-oriented communications.* M.Samad, E. Sepasgozar (2020) mention ***group Wiki Project (GWiP)*** which is offered as an essential tool for doing an online group project. The GWiP is one of the necessary tools of Web 2.0 that provides spaces to write by students of the group in a web- based setting. It is important to mention that this is a constructive activity and constitutes active learning in which students build an individual representation of their knowledge based on their peers' experiences. According to M. Samad, E. Sepasgozar (2020), group Wiki Project is an innovative group project online template, which was designed for students to do their group projects together. Importantly, the teacher becomes a tutor who advises, supports and assesses, as M.Samad, E. Sepasgozar (2020) say, give them relatively quick feedback, and increase the quality of their group project at the global level. GWiP was perceived as useful technology helping students to prepare their group projects (M. Samad, E. Sepasgozar, 2020). In other words this group-based learning method can be described as ***Role Play Project*** is an innovative group project online template, which was designed for students to do their group projects together, where tutors and other instructors could monitor students' work in real-time. Each group then presented their work (as a scenario base/role play based) and uploaded it on YouTube (M. Samad E. Sepasgozar, 2020).

B) ***Laboratory tasks*** are a powerful pedagogical strategy for developing competences in science and engineering degrees, making students understand in a practical way the theoretical topics explained in the classroom (V. Román-Ibáñez, Fr. A. Pujol-López, H. Mora-Mora, 2018). ***Virtual laboratories*** capable of simulating typical operating environments as well as extreme situations in the operation of different devices. A typical subject in which students can benefit from the use of virtual laboratories is robotics. Virtual reality has proven to be a powerful tool to achieve sustainability, making it easy to update laboratories without the need to acquire new equipment (V. Román-Ibáñez, Fr. A. Pujol-López, H. Mora-Mora, 2018). Today it is possible to provide experimentation environments for users for learning scenarios. This is used if a learning scenario is usually inaccessible, e.g. due to safety reasons in potentially dangerous environments. VR technology generally supports the idea of providing simulated environments for hands-on experiments as an additional learning material. Itis known that VR technology generally benefits the learning experience of a student. The same holds for the didactic mediation of purely theoretical knowledge, e.g. abstract knowledge that is put into perspective by a practical example. (M. Schluse, M. Priggemeyer, J. Rosmann, 2020). To further develop the idea of virtual laboratories, it is important to note that the virtual experiment system provides students with a rich, efficient, and expansive experimental experience (Ch. Hao, A. Zheng, Y. Wang, Bo Jiang, 2021). Virtual laboratories also play an important role in Ch. Hao, A. Zheng, Y. Wang, Bo Jiang (2021), when analysing digital circuit 3D-virtual online laboratories, authors mention the purpose which is to complement the limitations of existing physical laboratories, not to replace them. This study also shows that virtual laboratories are designed to that students will have possibilities to complete involvement in all aspects of the experimental design process, including experimental strategies, data analysis, and interpretation, along with an iterative design process. Also important to mention that the software application includes a 3D student client with a simulation environment, a web-based teacher interface with an integrated assessment tool, and a database server with a calculation engine. This application also has an integrated assessment tool that can be used directly to support formative and summative evaluation.

On the other hand, compared with the traditional course, the control group experiment shows that the blended program gives better results in the learning effects, such as higher rate of attendance, lower rate of course dropout, and higher scores on exams. Most students considered the virtual laboratory to be an attractive and effective learning medium. Furthermore, teachers think that the flexible and convenient learning mode brought by the virtual experiments is helpful for students to think and study actively and independently (Ch. Hao, A. Zheng, Y. Wang, Bo Jiang, 2021). M. Schluse, M. Priggemeyer, J. Rosmann (2020) also mention innovative aspect of the Virtual Robotics Lab concept. It enables hands-on experiments for Industry 4.0 technologies and systems in real-time, interactively and yet safely, consistently self-controlled, without special requirements on hardware and end devices while using high-quality visualizations and interactive simulations. In the context of blended learning and Experiential Learning Theory (ELT), the Virtual Robotics Lab thus provides an effective and efficient format of digital teaching (M. Schluse, M. Priggemeyer, J. Rosmann, 2020)

C) Teamwork means working together and learning from each other. As can be seen, virtual teams are also encouraged in the virtual world**. *Virtual project team*** is due to the fact that many students will work in global companies. This means that often their professional activities will be associated with the work of the global team. So, preparation for working in global teams when working on projects is important. As members of project teams can be geographically separated, they must be taught to interaction, working in a virtual project team. It models real world global virtual teams and introduces students to the social interactions through virtual communication technologies needed to successfully use their engineering skills (S. Morley, K. Cormican, P. Folan, 2015).

Additional information related to theoretical and conceptual framework can be found in **Annex 1**. While, framework for Virtual Reality Platform is presented in **Annex 10**.

2. Didactic Content

2.1. Methodology of didactic content development

Scenarios development process is based on possibilities of existing robot laboratories, since the blended education is planned to be implemented.

Therefore, the first step is to design a Virtual Reality Tool (VRT) which can be a virtual copy of the laboratory and its equipment or contain only the components used in the educational process of the target teaching modules.

The VRT designing and the scenarios development process is closely related to the **Intended Learning Outcomes** (ILOs) which are going to be achieved in the educational process.

The ILO consists of **Verb** + **Content** + **Context** (**Figure 4**). Verb represents what student will know or what student will be able to do after the teaching process. Verbs are connected with six major categories: **Knowledge**, **Comprehension**, **Application**, **Analysis**, **Synthesis**, and **Evaluation**, known as Bloom's Taxonomy (**Figure 5**). To achieve the ILOs in the educational process Teaching and Learning Activities (TLA) are designed for the process. Then, Assessment Tasks (AT) are created to check the ILOs achievement by the students. Relationship between an Intended Learning Outcome, verb, TLA and AT are presented in **Figure 6**.

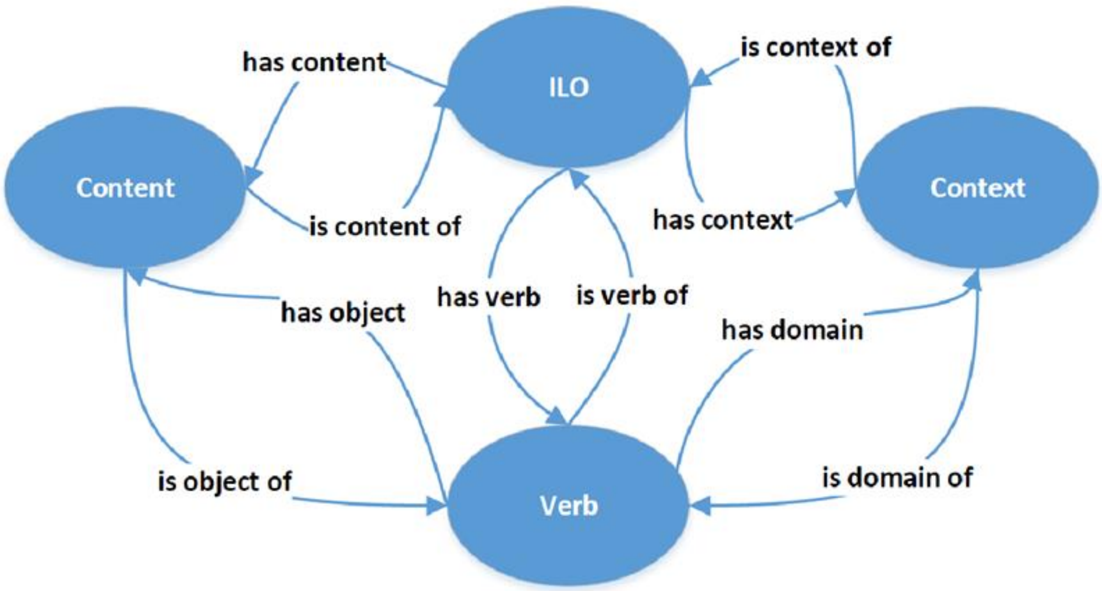

Figure 4 – Relationship between Intended Learning Outcomes and its constructive elements.

Adopted from: Maffei A., Daghinia L., Archentia A., Lohseb N. (2016), CONALI Ontology. A Framework for Design and Evaluation of Constructively Aligned Courses in Higher Education: Putting in Focus the Educational Goal Verbs. 26th CIRP De-sign Conference. Procedia CIRP, vol. 50, s. 765-772.

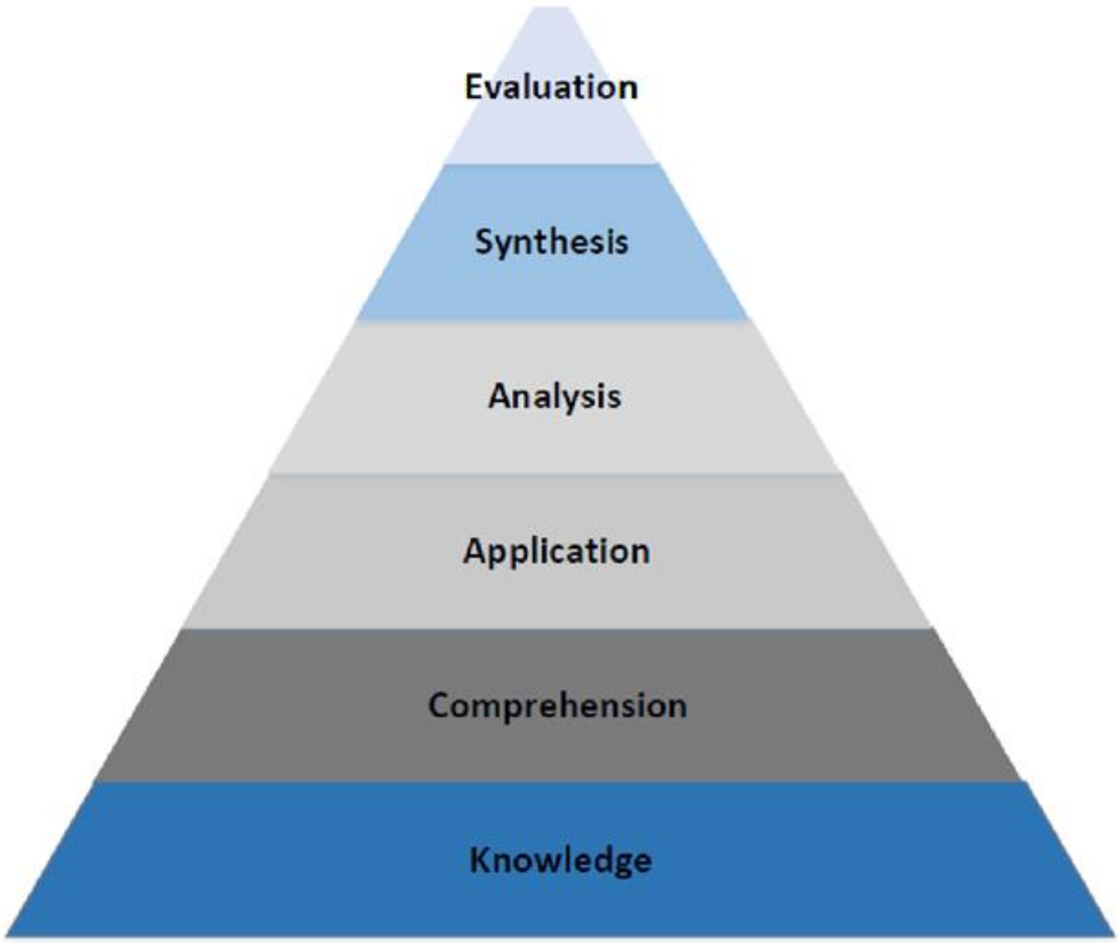

Figure 5 – Bloom Taxonomy.

Adopted from: Bloom, B. S. (1994). "Reflections on the development and use of the taxonomy". In Rehage, Kenneth J.; Anderson, Lorin W.; Sosniak, Lauren A. (eds.). Bloom's taxonomy: A forty-year retrospective. Yearbook of the National Society for the Study of Education. 93. Chicago: National Society for the Study of Education. ISSN 1744-7984.

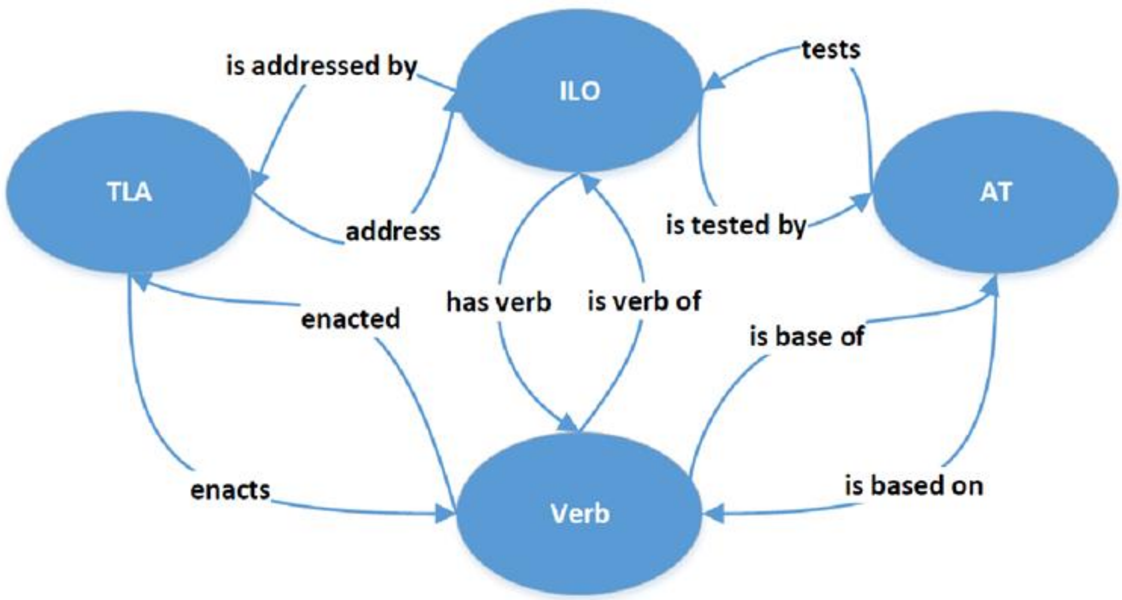

Figure 6 – Relationship between Intended Learning Outcomes, verb, TLA and AT.

Adopted from: Maffei A., Daghinia L., Archentia A., Lohseb N. (2016), CONALI Ontology. A Framework for Design and Evaluation of Constructively Aligned Courses in Higher Education: Putting in Focus the Educational Goal Verbs. 26th CIRP De-sign Conference. Procedia CIRP, vol. 50, s. 765-772.

The procedure of scenarios development consists of the following steps:

Step 1 – Development of Intended Learning Outcomes (ILOs).

Step 2 – Assessment of possibility to introduce blended education (BE) to achieve chosen ILOs.

Step 3 – Scenarios development with indicated Teaching and Learning Activities (TLA).

Step 4 – Development of Assessment Tasks (AT) for the ILOs.

The results of the presented steps are described in the following sections. The procedure was implemented for tdo educational modules: Industrial Automation in Politecnico di Torino (POLITO) and Basics of Robots in Politechnika Rzeszowska im. Ignacego Lukasiewicza (PRZ).

2.2. Didactic content - Teaching and Learning Activities and Assessment tasks for POLITO case study

The student workshop is concerned with industrial applications of collaborative robots and make use of the dual arm robots and of the mobile manipulator (**Figure 7**). The dual arm robots are relatively small and it is difficult for numerous students to observe properly the work area. The mobile robot is moving around the laboratory and it is still harder to properly follow during it work path.

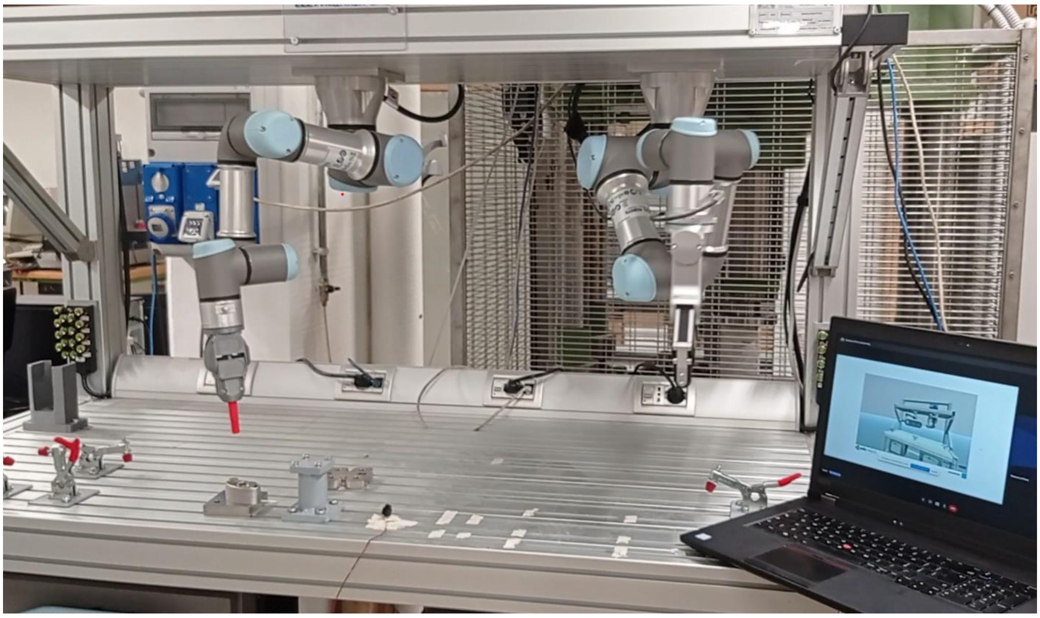

Figure 7 - Dual arm robots in POLITO

Table 1 presents Intended Learning Outcomes for Industrial Automation. Details related to the didactic content are presented later in this chapter and in the **Annex 2**.

The ILOs of Industrial Automation are implemented in the way presented in **Table 2**.

Table 1 – A set of ILOs for Industrial Automation

ILOs - Industrial Automation	**Additional explanation**
ILO-IA-1: Understanding the structure and performance of industrial robots	Theory
ILO-IA-2: Application of robots to selected industrial processes	Laboratory demonstration of industrial processed executed by robots
ILO-IA-3: Programming industrial robots: online, offline	Laboratory demonstration of online, offline programming The students will create a simple program using manual guidance
ILO-IA-4: Application of collaborative robotics	1 – speed and separation monitoring: laboratory demonstration 2 – power and force limiting: students try to collaborate with a robot in the execution of a collaborative assembly

Table 2 – The ways of ILOs implementation for Industrial Automation

ILOs - Industrial Automation	**Way of implementation** **(in VR, in reality, self-learning…)**
ILO-IA-1: Understanding the structure and performance of industrial robots	Teaching of theory about robot configuration and expected performances by using online documents, textbooks, video clips
ILO-IA-2: Application of robots to selected industrial processes	Laboratory demonstration of industrial processed executed by robots. This step will continue in a whole group arrangement with the teacher leading the class like in Step 1, but with the focus changing from pre-teaching to activity. In this step, students will become immersed in VR environments and take part in authentic exploration. ***Virtual project teams.*** The students of this course are working in a global company. Their professional activities will be associated with the work of the global team. ***Practical experiments – real-life situations.*** A Virtual Reality environment project allows students to connect to real-life situations._This method will be applied in simultaneous virtual, physical and remote virtual reality.
ILO-IA-3: Programming industrial robots: online, offline	Selected students will program online through manual guidance with replication in VR for the remote students. Offline programming will be executed in self learning by all students using robot simulator software
ILO-IA-4: Application of collaborative robotics	***Virtual project teams.*** The students of this course are working in a global company. Their professional activities will be associated with the work of the global team.

ILOs - Industrial Automation	Way of implementation (in VR, in reality, self-learning…)
	Practical experiments – real-life situations. A Virtual Reality environment project allows students to connect to real-life situations._This method will be applied in simultaneous virtual, physical and remote virtual reality.

Teaching and Learning Activities related to Industrial Automation are presented in **Table 3**.

Table 3 – Teaching and Learning Activities (TLA) for Industrial Automation and F2F laboratory

ILOs - Industrial Automation	**Teaching Activity**	**Learning Activity**
ILO-IA-1: Understanding the structure and attainable performances of industrial robots	**TA 1.1:** Explain and detail the main theoretical topics such as principles of automation, work cell, collaborative robot, characteristics and differences with respect to traditional robots, safety and ergonomic issues and standards (Video) **TA 1.2:** Ask students to name different structures and possible applications and to highlight their potential and limitations. Clarify the named methods one by one and add the unmentioned methods.	**LA 1.1:** Listen to the explanation, take notes, and ask questions. **LA 1.2:** Name different structures and possible applications and to highlight their potential and limitations.
ILO-IA-2: Application of robots to selected industrial processes	**TA 2.1:** Describe the different manufacturing processes with reference to their possibility of automation.	**LA 2.1:** Listen to the explanation, take notes, and ask questions.

ILOs - Industrial Automation	Teaching Activity	Learning Activity
	TA 2.2: Describe the procedure for executing robotized processes **TA 2.3:** Explain the pro and cons of manual, collaborative and automatic approaches to every production process **TA 2.4:** Execute examples and real applications of industrial automation of real cases and examples of collaborative applications (F2F + VR)	
ILO-IA-3: Programming industrial robots: online, offline	**TA 3.1**: Provide simulation by practical exercise on software and code generation. **TA 3.2:** Provide number of diverse application cases and ask students in group to select one case. Each group must select suitable programming method and develop the corresponding program. **TA 3.3:** Ask each group to present the case and the solution. Encourage students to ask questions. Explain the ideal solution of each case.	
ILO-IA-4: Application of collaborative robotics	**TA 4.1**: Set brief and provide ongoing feedback on Project work. Students are organized into groups and provided with a real case study project.	**LA 2.1:** Write in a short paper the differences among traditional and autonomous or collaborative robots.

ILOs - Industrial Automation	Teaching Activity	Learning Activity
	TA 4.2: Ask the students to write in a short paper about what are the differences between traditional and collaborative robots **TA 4.3:** Explain the basic elements of ISO TS 15066 and how can be designed robot workstations for every specific collaboration level. Answer any students' questions. **TA 4.5:** Set a course work of developing simple assembly operation using a collaborative robot programmed with the help of manual guidance.	**LA 2.2:** Listen to the explanation, take notes, and ask questions. **LA 2.3:** Execute the VR demonstration and apply it in an ongoing step by step. Seek help for unclear step

Finally, the assessment tasks for Industrial Automation are listed in **Table 4**.

Table 4 – Assessment Tasks (AT) for Industrial Automation

ILOs - Industrial Automation	Assessment Tasks (AT)
ILO-IA-1: Understanding the structure and performance of industrial robots	AT-IA-1: No assessment
ILO-IA-2: Application of robots to selected industrial processes	AT-IA-2: Execute the VR demonstration and answer to the questions about the selected industrial processes
ILO-IA-3: Programming industrial robots: online, offline	AT-IA-3: Program a collaborative robot to execute an assembly task
ILO-IA-4: Application of collaborative robotics	AT-IA-4: Write a paper on cobots

2.3. Didactic content - Teaching and Learning Activities and Assessment tasks for PRZ case study

The scenario of PRZ presents the machining process of grinding the vehicle rim based on a programmed path of processing made by industrial robot (**Figure 8**).

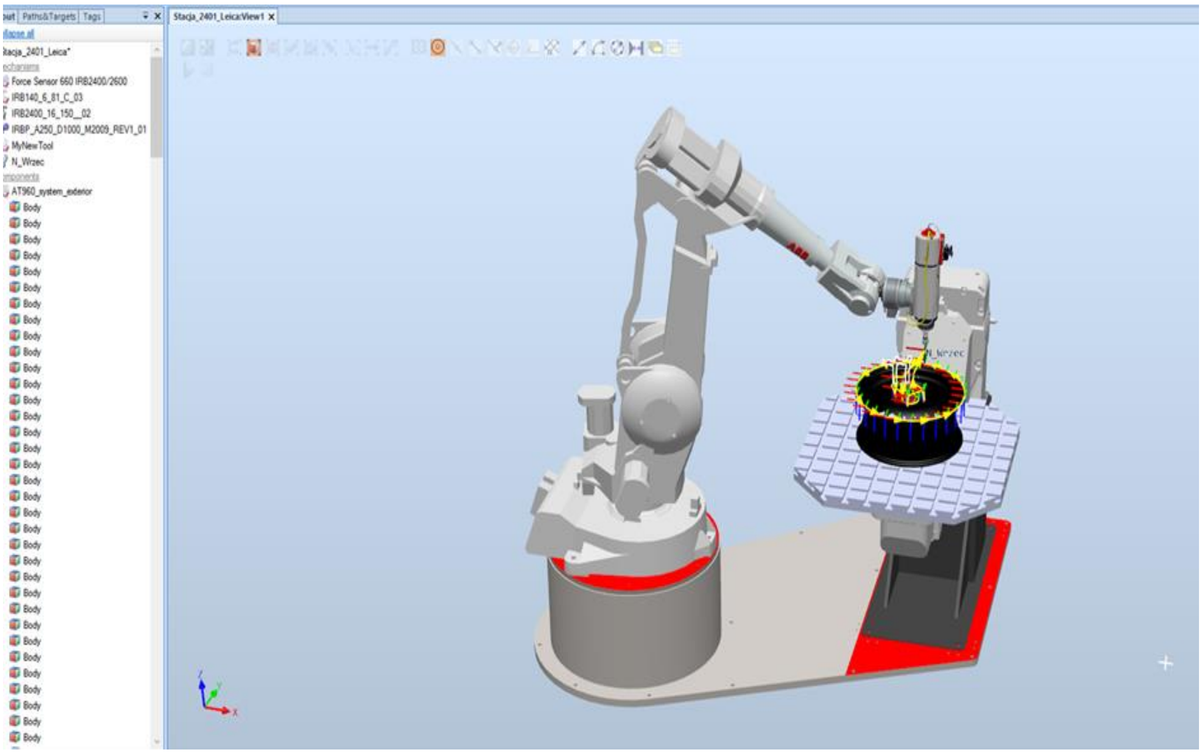

Figure 8 – View of ABB robot digital twin with workpiece - steel wheel rim of a vehicle

Table 5 presents Intended Learning Outcomes for Basics of Robots. Details related to the didactic content are presented later in this chapter and in the **Annex 2**. The ILOs of Basics of Robots are implemented in the way presented in **Table 6**.

Table 5 – A set of ILOs for **Basics of Robots**

ILOs – Intended Learning Outcomes	Additional explanation
ILO-BR-1: Has knowledge of basic issues in the field of robotics, which allows to understand the problems of robotization.	Theory
ILO-BR-2: Obtains information from the literature in order to understand the state of the art in the field of robotics.	Theory
ILO-BR-3: Applies self-study and understand the need for upskilling in the field of robotics.	Theory Laboratories demonstration
ILO-BR-4: Perceives and understands social aspects related to robotization.	Theory Laboratory demonstration of industrial processed executed by robots
ILO-BR-5: Designs a robotic system for a selected application.	Laboratories demonstration with the use of computer programs

ILOs – Intended Learning Outcomes	Additional explanation
	The students will design a simple robotic system for selected application
ILO-BR-6: Selects and applies appropriate computational, analytical and simulation methods to the designed robotic system.	The student will apply appropriate methods to analyze a robotic system.

Table 6 – The ways of ILOs implementation for Basics of Robots

ILOs – Intended Learning Outcomes	Additional explanation
ILO-BR-1: Has knowledge of basic issues in the field of robotics, which allows to understand the problems of robotization.	Theory For the theoretical part there are proposed several activities, which can be performed in virtual, physical and mixed reality depending on the activity itself. ***Pre-teaching includes starter activities or use textbooks, video clips, or other mediums. It can be combined with quizzes and interviews. Motion tracking systems and stereo sound.*** Instructors will deliver pre-teaching to the whole class before entering the VR experience.
ILO-BR-2: Obtains information from the literature in order to understand the state of the art in the field of robotics.	The information can be provided in VR, or video formats for better understanding ***Pre-teaching including starter activities or use textbooks, video clips, or other mediums. It can be combined with quizzes and interviews. Motion***

ILOs – Intended Learning Outcomes	Additional explanation
	tracking systems and stereo sound. Instructors will deliver pre-teaching to the whole class before entering the VR experience. ***Group learning*** when VR education gives the opportunity to make learning experiences social by allowing students to communicate with each other. Also this activity can be performed in physical or mixed learning. ***Learning virtual process itself.*** The advantages of this methodology of learning are that student learns virtual process itself but does not description of the process. This method is more informative.
ILO-BR-3: Applies self-study and understand the need for upskilling in the field of robotics.	Self-study in VR environment ***Learning virtual process itself.*** The advantages of this methodology of learning are that student learns virtual process itself but does not description of the process. This method is more informative. ***Raising questions and virtual tests.*** It can be organized in a virtual space, but there must be a virtual tutor who answers the questions asked. ***Stimulation peer-to-peer discussions.***
ILO-BR-4: Perceives and understands social aspects related to robotization.	Threats connected with robotization discussed during lectures. ***Various media material provided both in VR and physical environment*** ***Raising questions and virtual tests.*** ***Group, peer to peer discussions.*** ***Learning virtual process itself.*** The advantages of this methodology of learning are that student learns virtual

ILOs – Intended Learning Outcomes	**Additional explanation**
	process itself but does not description of the process. This method is more informative.
ILO-BR-5: Designs a robotic system for a selected application.	***In the Virtual Robotics Lab at the beginning and if possible after some practice in VR, then in physical laboratory.*** ***Virtual project teams.*** The importance of this area is due to the fact that many students will work in global companies. This means that often their professional activities will be associated with the work of the global team. **Simulation modelling creating virtual models.** Another method, that allows optimizing the functioning of large systems, is simulation modeling. Special simulation software allows creating virtual models of the processes that similar the real processes of the production system. ***Practical experiments – real-life situations.*** Virtual reality environment projects allow students to connect to real-life situations.
ILO-BR-6: Selects and applies appropriate computational, analytical and simulation methods to the designed robotic system.	The student will apply appropriate methods to analyze a robotic system. In ***teacher-led small groups***, instructors guide students through consciously reflecting upon the VR experiences. ***Modeling and simplifying problems through Abstraction methods.*** ***Virtual project teams.*** The importance of this area is due to the fact that many students will work in global companies. This means that often their professional activities will be associated with the work of the global team.

ILOs – Intended Learning Outcomes	Additional explanation
	In the Virtual Robotics Lab at the beginning and if possible after some practice in VR, then in physical laboratory. **Simulation modelling creating virtual models.** Another method, that allows optimizing the functioning of large systems, is simulation modeling. Special simulation software allows creating virtual models of the processes that similar the real processes of the production system. ***Practical experiments – real-life situations.*** Virtual reality environment projects allow students to connect to real-life situations.

Teaching and Learning Activities related to Basics of Robots are presented in **Table 7**.

Table 7 – Teaching and Learning Activities (TLA) for Basics of Robots

TLAs - Basics of Robots	Additional explanation
TLA-RP-1: Introduction: basic concepts and definitions of automaton, automation, manipulator, robot, robotization – classification and applications.	Lecture Theory To introduce students to the field of robotization. Application examples, including industrial applications.
TLA-RP-2: System thinking: (1) workpiece processing automation, (2) control properties in open circuit and with feedback, (3) work with devices supported by robots.	Lecture Theory Explaining diagrams

TLAs - Basics of Robots	**Additional explanation**
TLA-RP-3: Components and construction of robots: basic robot systems.	Lecture Theory Presentation of robot's components Laboratory presentation Power system, control system, motion system
TLA-RP-4: Classification of robots according to the following criteria: geometric properties, area of application.	Lecture Theory
TLA-RP-5: Grippers. Classification of grippers: force grippers, grippers with stiff and flexible tips, vacuum grippers, magnetic grippers, shaped grippers. Equipment for grippers.	Theory Presentation of the types of grippers and their possible applications.
TLA-RP-6: Linear drives of robots. Wave gears.	Lecture Theory
TLA-RP-7: Sensors and motion limiters in manipulators and robots.	Lecture Theory
TLA-RP-8: Construction and application of robots of the following classes: PPP, OPP, OOP, OOO	Lecture Theory Presentation of the construction, movements and working space of robots.
TLA-RP-9: Robot control layers	Lecture Theory

TLAs - Basics of Robots	Additional explanation
TLA-RP-10: Industrial robots. Robots similar to mammals, reptiles and amphibians.	Lecture Theory Presentation of examples of robots.
TLA-RP-11: Intelligent materials in robotics.	Lecture Theory Application examples of intelligent materials in robotics.
TLA-RP-12: Homogeneous transformation.	Lecture Theory A way of writing position and orientation in space using a matrix.
TLA-RP-13: Modeling, calculating, designing a selected gripper along with the selection of sensors, drives and control systems as well as simulation of its operation.	Group project Design of a gripper system in the selected application and simulation of its work on the basis of the provided gripper diagram.

Finally, the assessment tasks for Industrial Automation are listed in **Table 8**.

Table 8 – Assessment Tasks (AT) for Basics of Robots

ILOs - Basics of Robots	Assessment Tasks (AT)
TLA-RP-1: Introduction: basic concepts and definitions of automaton, manipulator, robot, robotization – classification and applications.	AT-RP-1: Test at the beginning of the laboratories

ILOs - Basics of Robots	Assessment Tasks (AT)
TLA-RP-2: System thinking: (1) workpiece processing automation, (2) control properties in open circuit and with feedback, (3) work with devices supported by robots.	AT-RP-2: Test at the beginning of the laboratories
TLA-RP-3: Components and construction of robots: basic robot systems.	AT-RP-3: No assessment
TLA-RP-4: Classification of robots according to the following criteria: geometric properties, area of application.	AT-RP-4: Open questions
TLA-RP-5: Grippers. Classification of grippers: force grippers, grippers with stiff and flexible tips, vacuum grippers, magnetic grippers, shaped grippers. Equipment for grippers.	AT-RP-5: Discussion with students
TLA-RP-6: Linear drives of robots. Wave gears.	AT-RP-6: Discussion with students
TLA-RP-7: Sensors and motion limiters in manipulators and robots.	AT-RP-7: Discussion with students
TLA-RP-8: Construction and application of robots of the following classes: PPP, OPP, OOP, OOO	AT-RP-8: Test at the beginning of the laboratories
TLA-RP-9: Robot control layers	AT-RP-9: Discussion with students
TLA-RP-10: Industrial robots. Robots similar to mammals, reptiles and amphibians.	AT-RP-10: No assessment
TLA-RP-11: Intelligent materials in robotics.	AT-RP-11: No assessment
TLA-RP-12: Homogeneous transformation.	AT-RP-12: Discussion with students

ILOs - Basics of Robots	Assessment Tasks (AT)
TLA-RP-13: Modeling, calculating, designing a selected gripper along with the selection of sensors, drives and control systems as well as simulation of its operation.	AT-RP-13: Open questions

The VR tool developed in the frame of the JANUS project support the education process.

3. Virtual reality for Robotic education – case study integration

The following section describes the implementation of virtual reality for blended learning activities for robotics education at universities. As mentioned before, the JANUS project was applied to two courses implemented at the Poitechnika Rzeszowska im. Ignacego Lukasiewicza (PRZ) in Poland and the Politecnico di Torino (POLITO) in Italy. The course in Poland covered the subject Basics of Robots, while the course in Italy covered Industrial Automation. The topics described of integration of virtual reality into the educational process for the above courses are presented below in the following steps:

1. General information on the project and teaching about robotics for the research case study, types of applications for synchronous, asynchronous mode.

2. Description of the scenario implemented in Poland for the asynchronous learning mode.

3. Description of the scenario implemented in Italy for synchronous / asynchronous learning mode.

4. Evaluation of the learning process for the example platform, visualization of the progress of students' work.

5. Example of a teacher intervention plan.

3.1. General information

In order to satisfy the requirements defined to realize blended learning scenarios for the teaching of Robotics, both for the POLITO laboratory and the PRZ laboratory, a web-based architecture has been designed, trying to make the configuration simple and flexible by the teacher, also based on future needs and developments.

From the user point of view, a simple, intuitive, and effective GUI (Graphical User Interface) allows students to connect and interact with a virtual 3D environment in remote mode and also in real time during laboratory activities. A web server hosts the 3D VR platform.

It consists of a standalone webGL Unity app that integrates the 3D VR scenarios based on the two use cases made available by the laboratories of POLITO and PRZ.

In this way, using Virtual Reality, it is possible to achieve the objectives and benefits which are of primary importance in blended learning, not only in a school teaching context, but also in the industrial field:

- Learning at a distance,
- Improve user learning and engagement,
- Gaining knowledge and skills in less time from performing actions in a simulated environment,
- Explore and interact with the virtual environment safely,
- Equipment availability,
- Accurate recreation of the real-world aspects,
- Greater effectiveness in visualizing and explaining complex operations to the user,
- Simpler and more intuitive learning mode,
- Reduction of training times and costs,
- Easy integration into LMS and into the Company Academy,
- Apps usable on desktop and browser.

The created platform for self-blended learning education for students can be separated into two parts: VR tool and ViLLe assessment platform for knowledge evaluation. Students and teachers for the pilot study obtained their own credentials to log in to the services.

The VR tool can be separated into the following categories:

- Asynchronous mode of robot simulation of PRZ, access under the link: https://rzeszow-lab.herokuapp.com/html/login.html
- Synchronous and asynchronous mode of robot simulation of POLITO, access under the link: https://polito-lab.herokuapp.com/html/login.html

Asynchronous scenarios are dedicated for blended learning mode in case of:

- Difficulties in attending real classes (e.g., COVID issues),
- Preparation for real-world classes, especially in terms of security and tool knowledge,
- Additional homework as an expansion of the knowledge possessed.

Asynchronous scenarios are a full online web application experience. The synchronous mode is more interactive, and a teacher is needed to perform such classes. In that case, robot movements performed by teacher in the class can be seen in VR tool by the students in web application, and the teacher can explain and assist students in that case.

The first step is to log in to the VR tool using user credentials (**Figure 9**).

Figure 9 - Log-in window for the VR tool

Then, by clicking on the button “i” users can get basic manual how to move around and interact with the simulation (**Figure 10**).

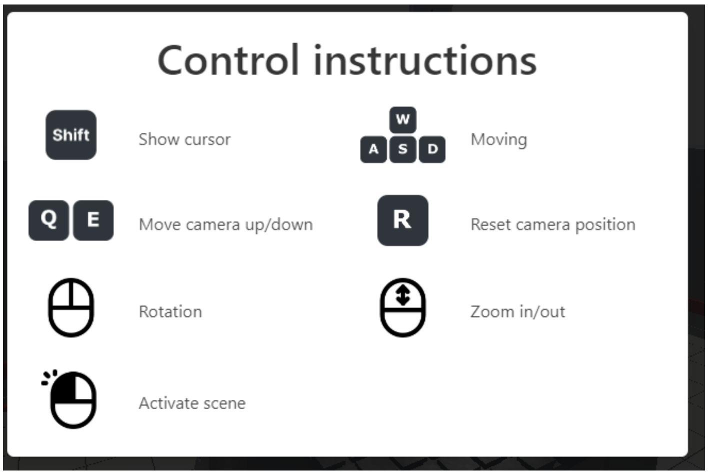

Figure 10 - Manual from the VR tool

Process of development and the detailed description of the VR tool are presented in **Annex 3** and **Annex 11**. The descriptions of both created scenarios are given below. The general scheme of the JANUS project steps to perform the research is presented in **Figure 11**. More information is presented in **Annex 4**. Detailed information regarding the pilots study is presented in **Annex 12**.

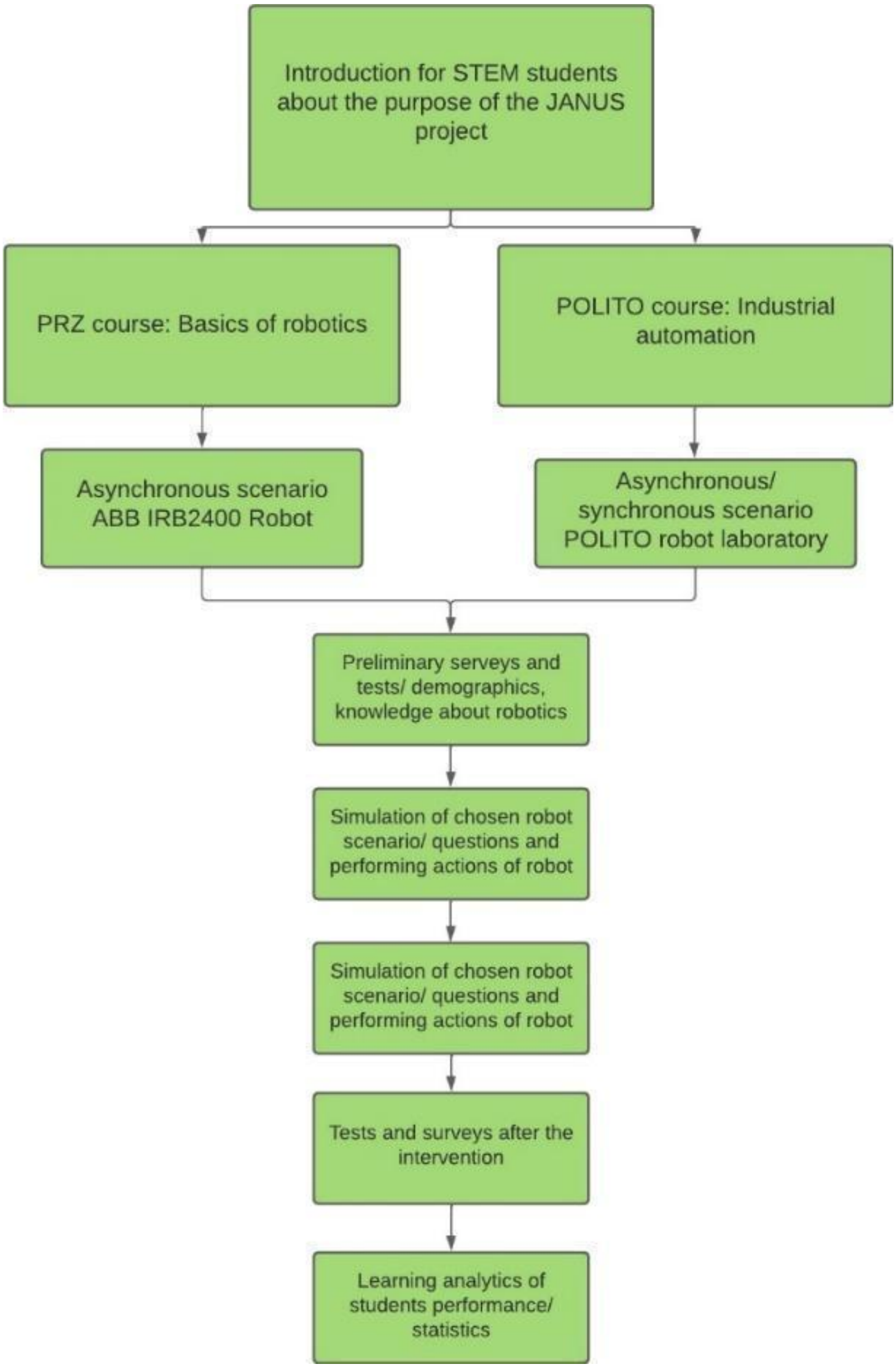

Figure 11 - General scheme of the JANUS project research conducted on students of selected courses

3.2. Description of the asynchronous scenario implemented in PRZ

The PRZ scenario assumes an asynchronous simulation in which students participate in the VR experience in their homes. Simulation is the reflection of real-world robotic laboratories.

The laboratory includes a robotics station equipped with an ABB IRB2400 robot and a vision system (**Figure 12**).

Figure 12 - View of ABB robot with workpiece - steel wheel rim of a vehicle

The scenario assumed the use of an ABB robot with workpiece, which is the vehicle rim. The second scenario assumed the workpiece as a piece of steel. At the beginning of the class, students become familiar with the safety instructions and tools that will be used to perform laboratory work. Performing such classes in a group of 15 students, which is an average number of students in one group, could be a danger and influence the safety of the students. In that case, the use of the developed blended learning approach could be beneficial to both teachers and students. For instance, teacher can divide the group into two smaller groups, e.g., 7 and 8 students, and part of them will participate in real-world classes and the rest will experience VR tool; in that case we can consider this approach as blended. Furthermore, having 15 students in small laboratory can influence the robot performance, because of sensors which stop the robot when people will be in range of them.

Blended learning also means that in the event, e.g., some COVID lockdown when the university laboratory can be closed and also in some other circumstances, the students will have the opportunity to participate in good quality robotic classes that can partly replace the real one, or they can just support their knowledge at their homes (work on digital twin robots). Virtual learning activities will act as a replica of the procedures and techniques that students follow under normal circumstances in the physical classroom (laboratory).

The main part of the development of the robotics VR scenario can be divided into two stages:

1. Physical robot located in PRZ laboratory performing the grinding process of vehicle rim grinding or steel workpiece.

2. Replica of the physical robot within the VR platform.

The scenario presents the machining process to grind the rim of the vehicle based on a programmed processing path. The second scenario assumes the grinding of the steel workpiece. At the beginning of the course, the students are introduced to the general safety rules in the laboratory (safety systems used for robot operation). Then the lecturer introduced the students to the abrasive coated tool used for machining, and the characteristics of the robot arm (degrees of freedom, kinematic pairs, structure, etc.). The machined part, i.e., the steel wheel rim of the vehicle and steel workpiece, is shown in **Figure 13**.

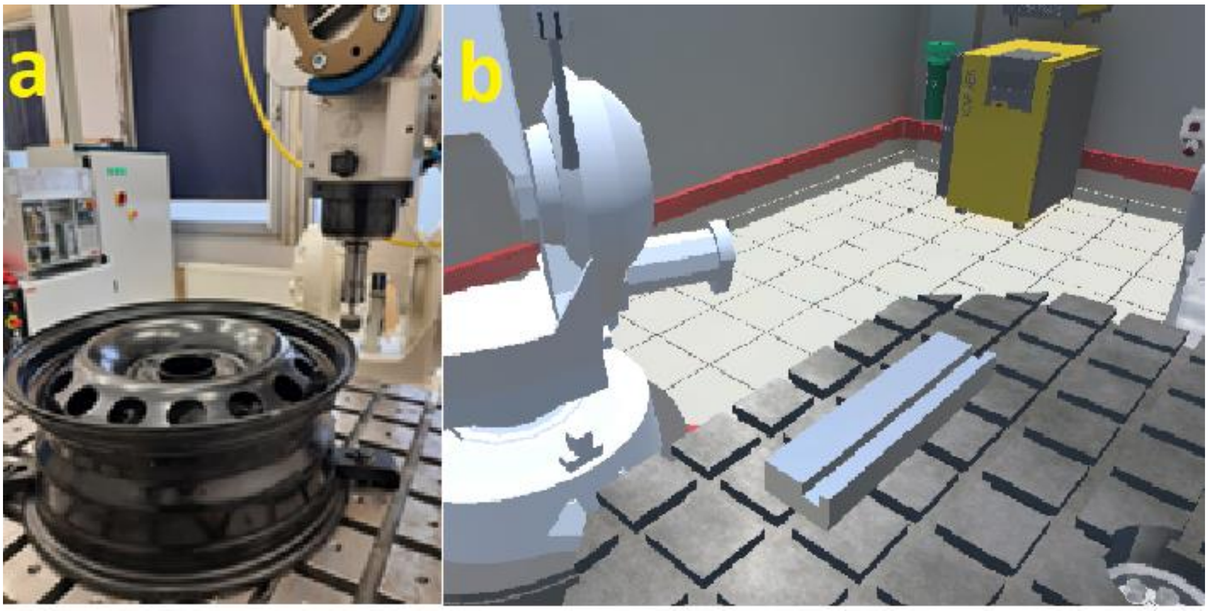

Figure 13 - Workpiece machined by ABB robot – a) vehicle rim b) steel workpiece

The features of the created VR tool for PRZ asynchronous scenarios are below (also presented in **Annex 4**).

- Click on the «Start» button to enable procedure selection,
- Click on the 'Exit' button to quit.

The main windows of the VR tool are presented in **Figure14**.

Figure 14 - Main window to view the PRZ VR scenario

- The students have the opportunity to explore the environment by clicking on interactive items (**Figure 15**),
- Some parts are highlighted and blink,
- Click on parts to view relative information,
- Click the 'Questions' button to take the assessment quiz.

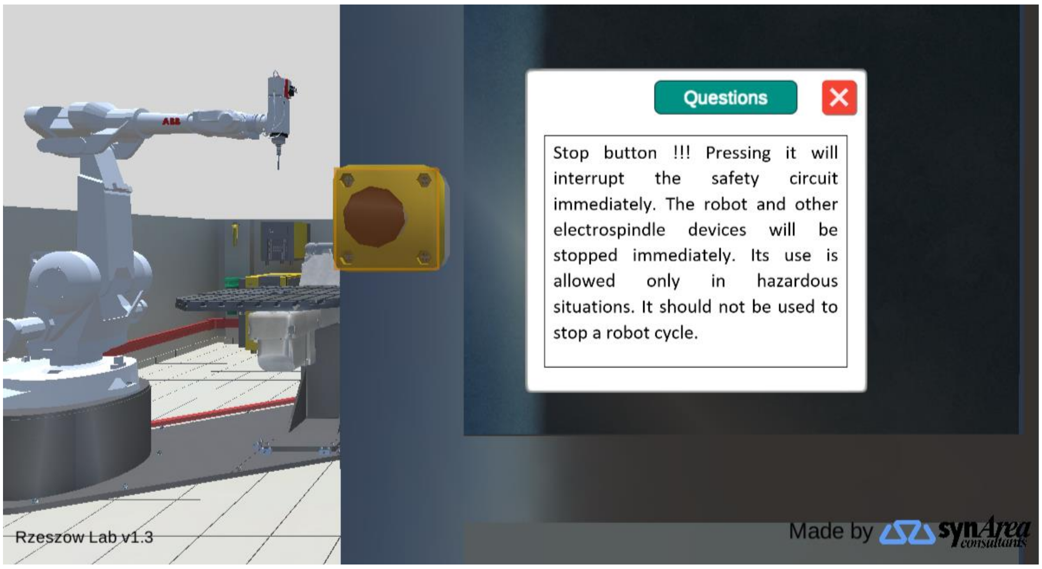

Figure 15 - Interactive items, example of a safety button next to the entrance to the lab

There are 3 interactive items in the simulation with the indicated number of questions related to it (**Figure 16**):

- Safety button next to the entrance to the lab (3 questions),
- Main switch and remote control (4 questions),
- Internal brake release unit (3 questions)

So, before the Start button is available to click for students, they have to deal with all of the interactive devices described above. Each of the devices has a description in the beginning after clicking on it, and then students should click the Question button and answer. They have to answer 10 questions. The answer time is recorded and also the click number to choose the correct answer. In that way, the tool records parameters for later learning analytics purposes. After answering all the questions, the students can go through the simulation of grinding the vehicle rim.

To choose the answer, they can click and interact with (**Figure 17**):

- Check the right response,
- «Confirm» to submit.

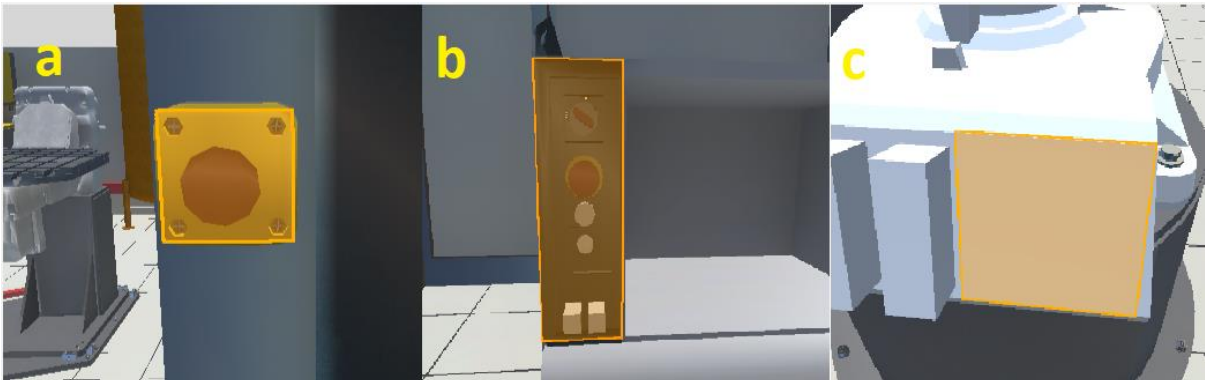

Figure 16 - Interactive devices: a) safety button, b) main switch, c) Internal break release unit

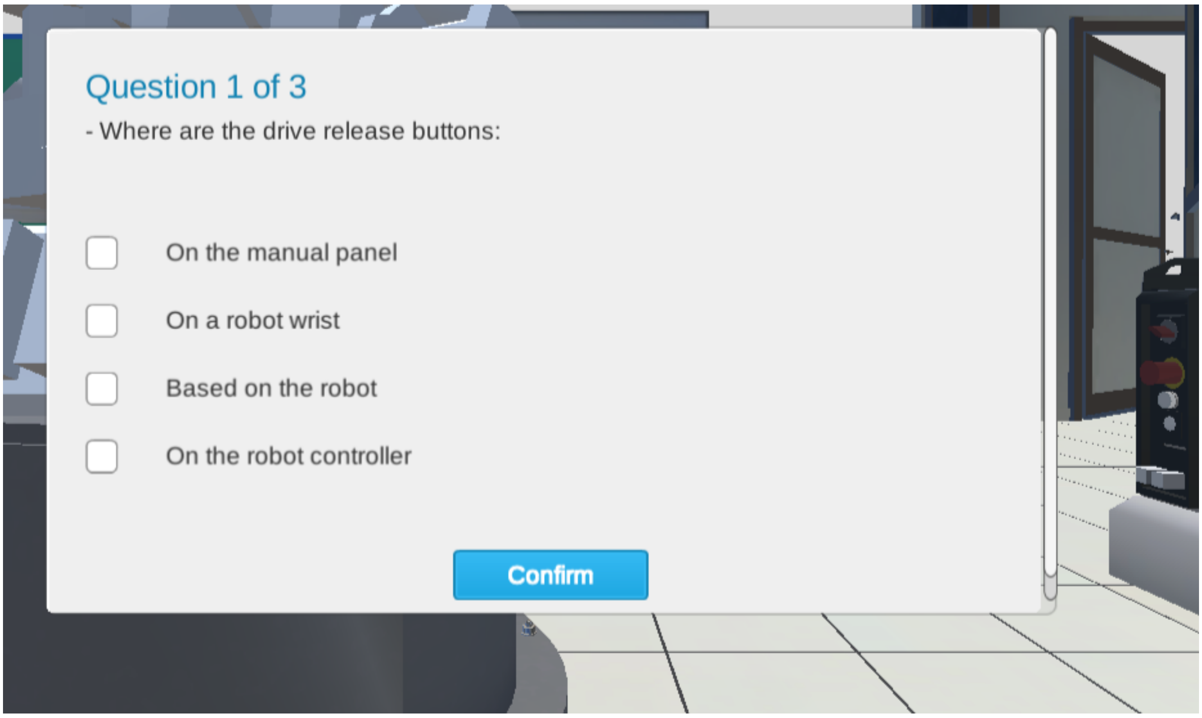

Figure 17 - Example of questions window before simulation starts

Example questions related to the interactive device of the safety button are presented in **Table 9**.

Table 9 - Example questions for safety button device included in the simulation in the VR

Rzeszów University of Technology - VR Quiz - EN				
#	Category	VR_Question_ID	Question ID	Answers / Score
Q1	Safety	prz_i01_q01	What kind of safety features are in the simulated station	. **Safety buttons** a. Safety curtain b. Safety scanner c. Safety mat
Q2	Safety	prz_i01_q02	Pressing the emergency stop button will	. **Immediate interruption of the safety circuit** a. Shut down the robot b. Disengaging the tool c. Driving the robot to home position
Q3	Safety	prz_i01_q03	If the emergency stop button is used, the electro spindle	. **Stops** a. Reduces speed by 50% b. Will drive off to home position c. Reduces RPM by 90%

Before the simulation starts, students can choose whether they want to have a trail of tools or not. The window with described choosing option is presented in **Figure 18**.

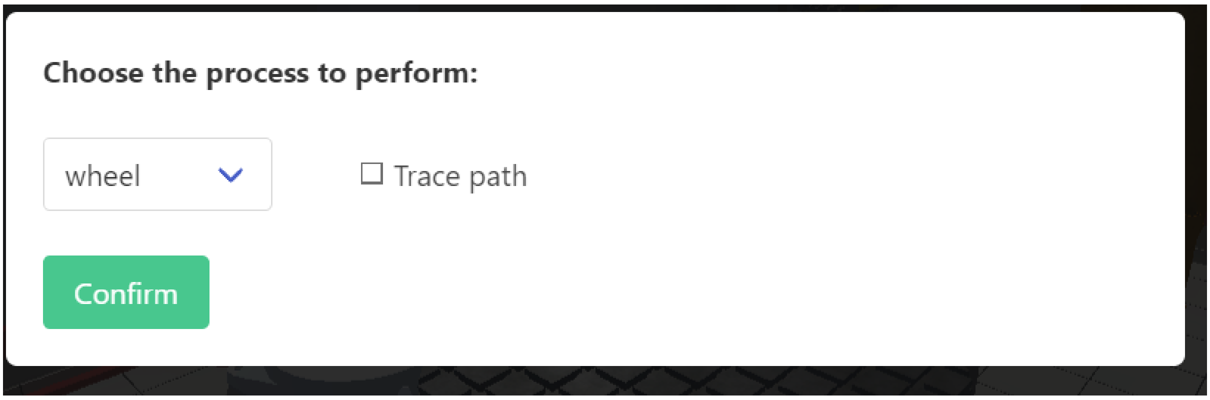

Figure 18 - Choosing window at the beginning of the simulation, option to turn on recording trace path

In case of choosing the option ‘trace path’, the tool will draw a white line indicating the path of the tool (**Figure 19**). In case of programming the path, students can experience virtually whether the path is correct or if it needs some more improvement to minimize unnecessary robot movement to reduce energy consumption. Furthermore, students can actually see if the path is correct in terms of the quality of grinded workpiece.

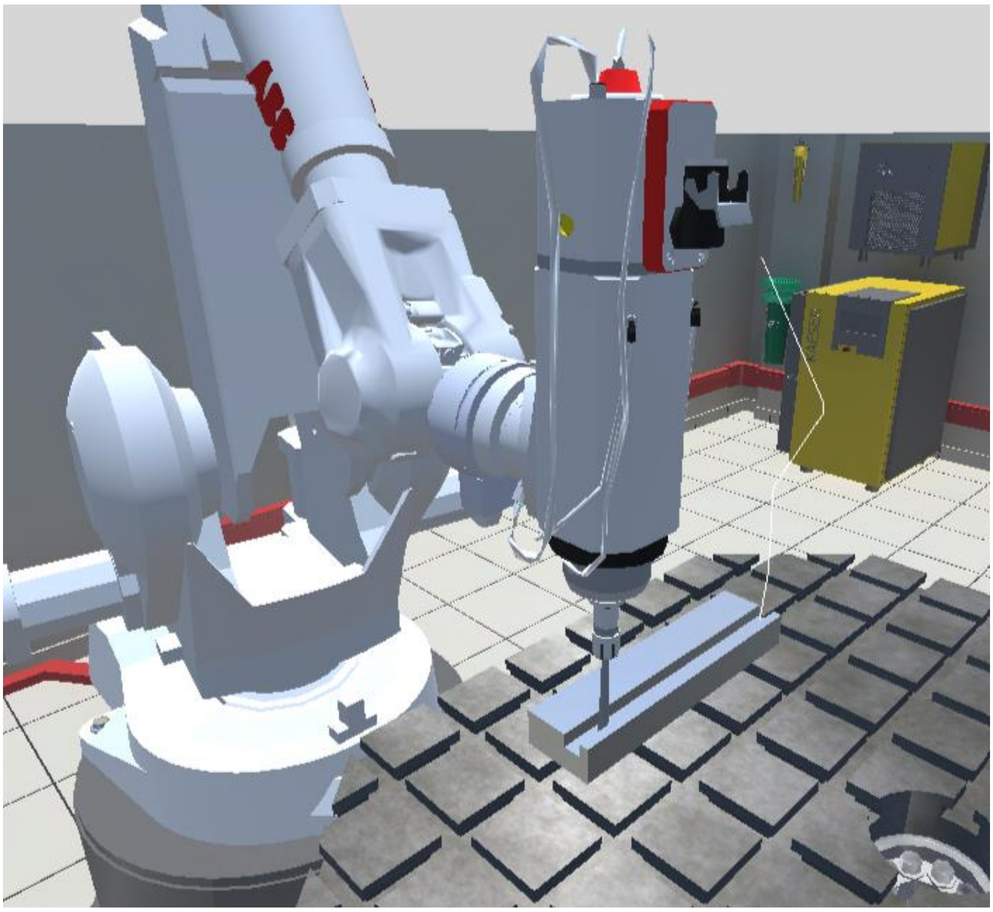

Figure 19 - Simulation with 'trace path' option turned on

During the simulation, students can interact with the following button options:

- Visualize the robot motion,
- Explore the 3D virtual environment,
- 'Pause' button to pause the motion,
- The «Speed» selection button to accelerate or slow down the motion.

Actually, after the first part of the case study, the academic teachers proposed some improvements to the VR tool. They proposed adding some angles of the arms of the robot for all of the axes, which can be used for the calculation of the robot movement matrixes. Also, the other improvement was to add the simulation speed button. Thanks to this improvements, it is possible to choose 0.5-3x speed range of the simulation. The new functionalities of the features are presented in **Figure 20**.

Figure 20 - New functionality of the VR application after academic teachers' intervention (speed range simulation button and angles of the ABB robot arms for all of the axis)

3.3. Description of synchronous / asynchronous scenario implemented at POLITO

There are two different scenarios that are implemented in POLITO.

In the first scenario, namely the synchronous one, students and teachers are present in the laboratory with adequate distancing. The students must be less than 10 for safety reasons.

The robots are a couple of Universal Robots UR3 mounted on a ceiling, as in **Figure 21**.

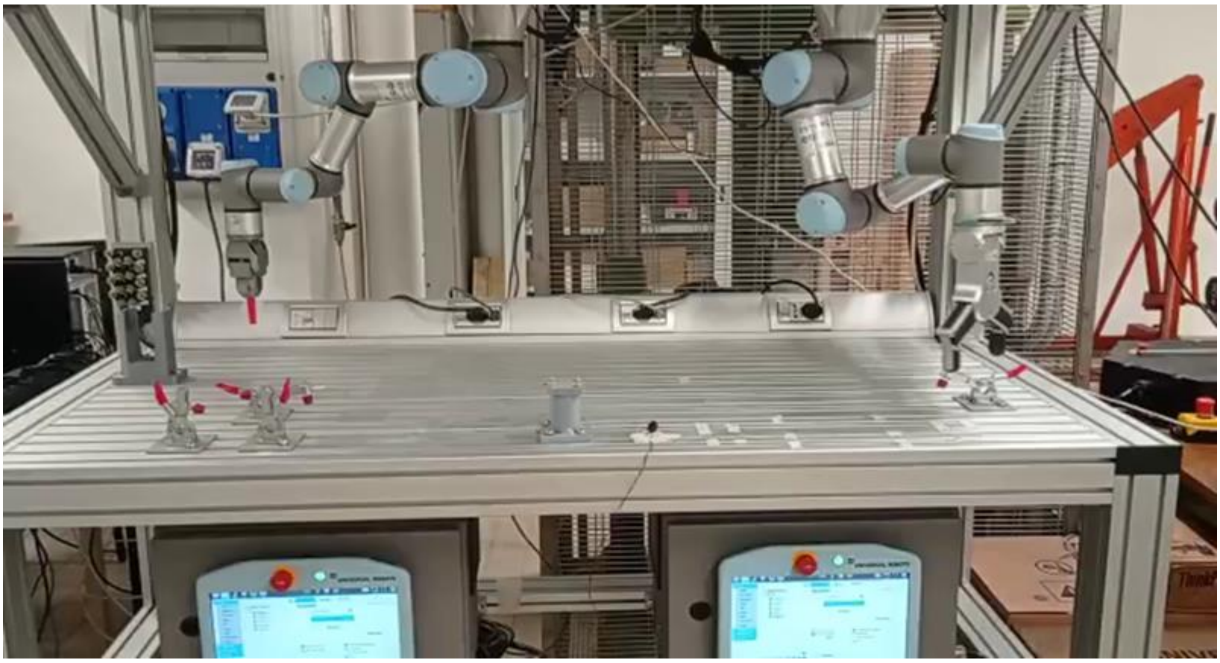

Figure 21 - The UR robots employed for the demonstration at POLITO

The workshop covers topics of industrial automation with the use of collaborative robots. The teacher is near the robot and leads by programming executing some simple movements. After this, the teacher runs a number of pre-programmed tasks covering the most frequent industrial use of manipulators: pick and place, assembly, and palletizing.

The students assist in the demonstration both by looking at the robot and at its VR representation on a large screen. For the success of the demonstration it is crucial that the students be able to see the input the teacher gives on the teach pendant. The teach pendant in the demonstration at POLITO is the size of a 10” tablet and the students cannot see the screen directly. They see a replication on the large screen. The replication is not VR, but a bidimensional copy of the teach pendant screen running in a separate environment.

In **Figure 22** it is possible to view the VR model of the robots. In **Figure 23** there is the scenario from the viewpoint of the students: the teacher on the teach pendant near the robots and the screen with the digital twin of the experiment replicating in real time the same operations. In the top left corner of the screen the teach pendant overlaps the VR showing to the students the commands that are given to the robot.

Incidentally it can be observed that COVID distancing was assured during the demonstration because of safety mask and of spatial distancing among people.

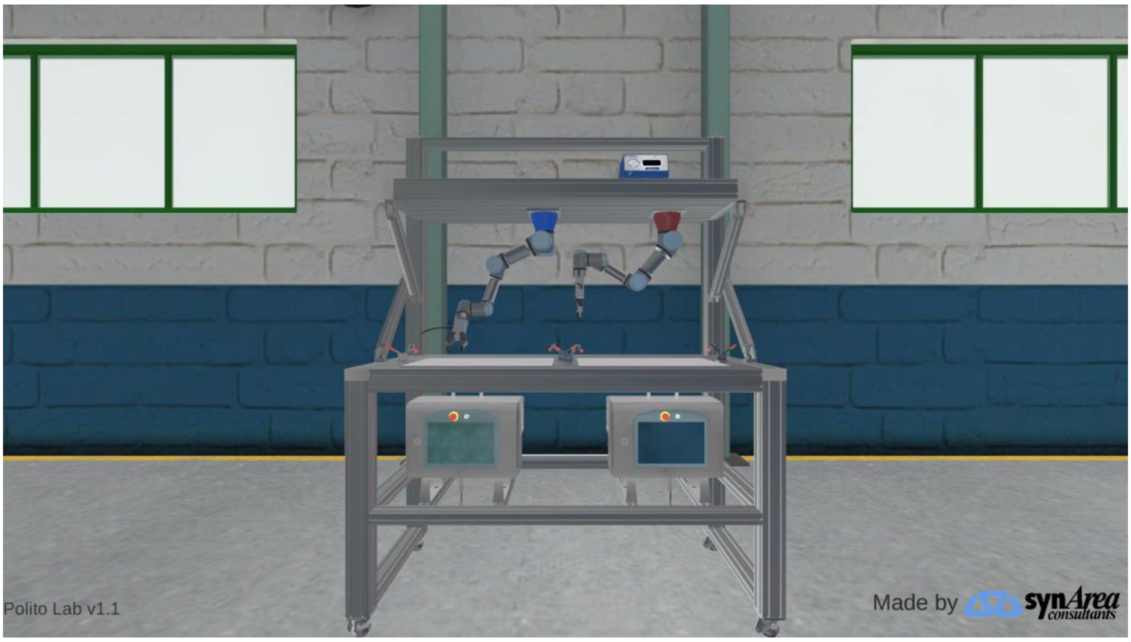

Figure 22 - The VR model of the UR robots at POLITO

Figure 23 - The synchronous demonstration at POLITO

The students participate to the scenario with just the role of observers. They do not interact with the VR or the robot. In a second time two students per time have been allowed to access the robot and to try guiding the robot arm on a simple trajectory.

This demonstration is not followed up with verification.

In the second scenario, following the first one, the same students are given a link to a remote server running the same industrial tasks shown in the laboratory. The students are free to run the scenario as many times as they want in whichever moment. To proceed with the scenario the students must answer correctly to a number of questions, as shown in **Figure 24**.

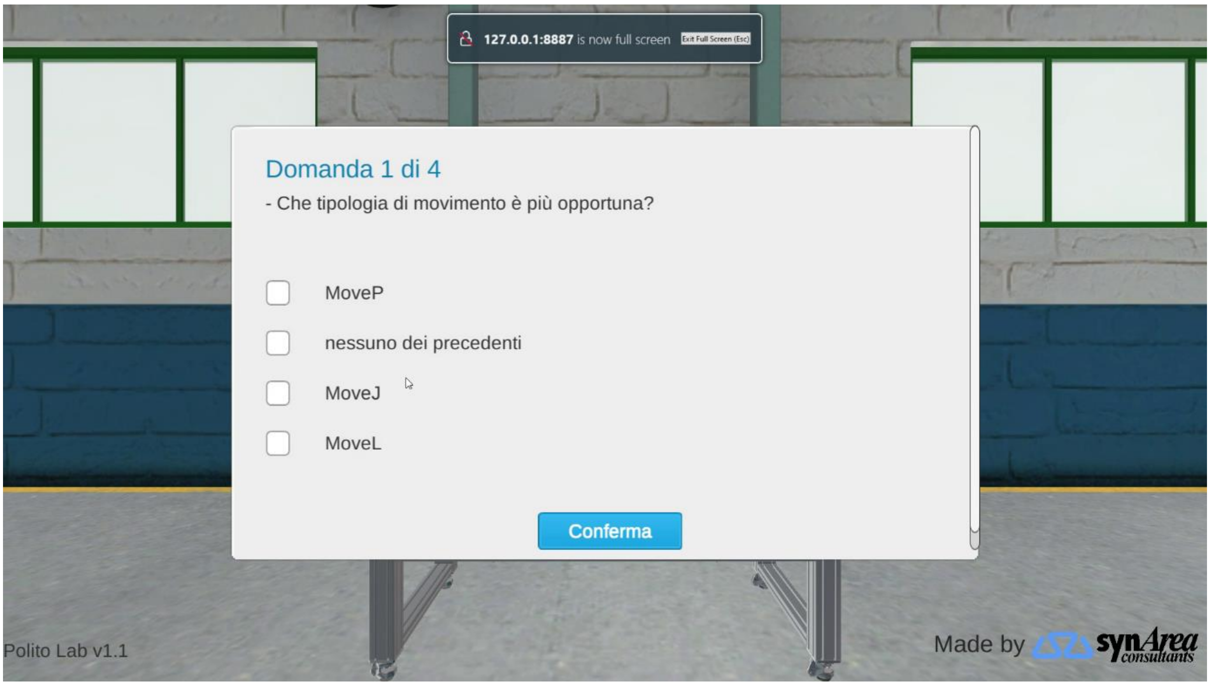

Figure 24 - The asynchronous scenario with the dialog box superimposed on the screen

An example of the questions and possible answer is reported in **Table 10**. It should be noted that questions are not given at the end of the lesson but are integrated in the laboratory experience, therefore the students will learn seamlessly the right answer to every question.

Students' experience has been collected using surveys submitted before and after the execution of the VR workshop using the ViLLe platform.

Table 10 - Example questions included in the simulation in the VR (in bold the right answer)

	Category	*Question*	*Answers*
1	*Theoretical concepts*	*How many axes does the UR 3 collaborative robot consist of?*	*a. 4*
			b. 6
			c. 8
			d. None of the others
2	*Theoretical concepts*	*To which type of robot does the UR 3 model belong?*	*a. SCARA*
			b. Cartesian
			c. Anthropomorphic
			d. Delta
3	*Theoretical concepts*	*What are the names given to the UR 3 robot's joints?*	*a. J1, J2, J3, J4, J5, J6*
			b. Base, shoulder, elbow, wrist1, wrist2, wrist3
			c. A, B, C, D, E, F
			d. Both a. and b.

The scenario with asynchronous VR has been applied also in a very large classroom with more than one hundredth students. In this case it was impossible to execute the visit in the laboratory with the synchronous VR. The results of the questionnaires show, anyway, positive feedback from the students.

4. Evaluation of the students' performance platform- ViLLe

The third step of the JANUS project is development and preforming of learning analytics in ViLLe platform. In fact, ViLLe learning analytics assumed preliminarily the demographic assessment for later statistics analyses, so the usage of ViLLe in terms of JANUS project is the first activity that students are going through.

ViLLE offers plenty of exercises and education content in multiple subject areas for a broad target group, including mathematics and programming. The platform offers extensive analytics of the student's progress and performance. ViLLE can be used as a complementary resource to school books, and it works best in providing exercises to practice the skills learned. Description of the ViLLE is presented in **Annex 5**.

The data gathered from the Virtual Reality tool can be stored in a cloud database. To integrate the data into the cloud, a platform with the Application Programming Interface (API) and the Database (DB) is needed. Platform Backend API & Server Configuration is presented in **Annex 6** and the tested results are presented in the Unit testing report in **Annex 7**.

Specification of the research plan and the data collection instruments are presented in **Annex 8**. While, analysis of the primary data and visualisation of the outcomes of the pilot studies are included in the **Annex 9**.

The main features and introductions related to ViLLE in terms of trainer training are included in the document **Annex 5**. The below description of the JANUS ViLLE platform refers to main parts of the research for training purposes.

To log in to the ViLLE platform it is necessary to use the following link: https://ville.utu.fi. Then, with the use of credentials, you can log into the platform and explore available courses. The example is shown in **Figure 25**, where it can be seen in ViLLE.

The frame on the left side lists all the lessons in the course. The Lessons frame lists all lessons opened by the teacher (**Figure 26**). To open a lesson, select the name of the lesson to see all the tasks in the lesson. To open the next lesson, click on the eye icon next to the desired lesson. The eye icon behind the open lessons is blue - only lessons with a blue eye are visible to students. Click on the eye to show or hide the assignment. A flag displayed in the lesson bar can be added by clicking on the flag image.

Figure 25 - Example view on courses available in ViLLE

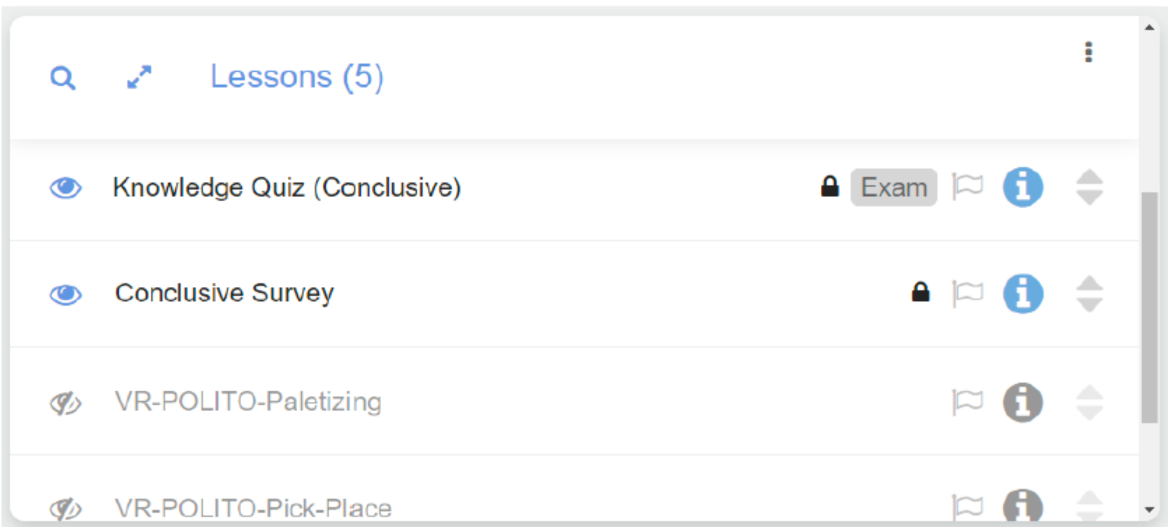

Figure 26 - Example view on lessons from the ViLLE platform

From the User view, you can view the students and tutors in your course. In the top frame, you can see a list of students on the course. You can sort the list of students by the column you want by clicking on the column header or search for a column using the white search fields. Click on the pencil icon in the Edit column to edit the student's details (username, email address, name, school, and password). Click on the trash icon in the Delete column to remove the student from the selected course. Note that this will not remove the student's ID from the system, but will remove all performance data for the selected course (**Figure 27**).

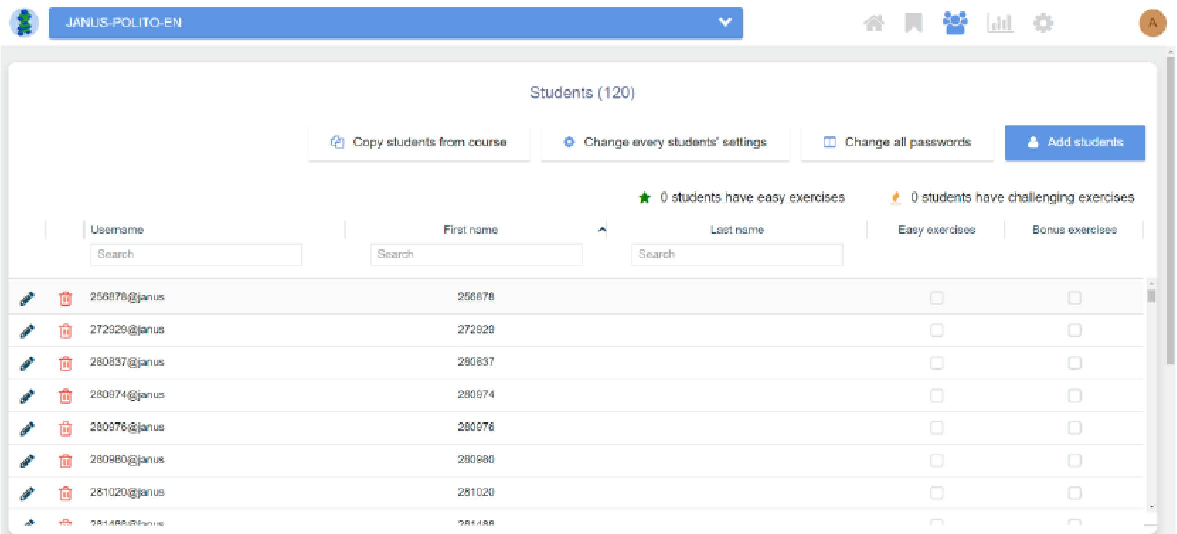

Figure 27 - Lists of students in the ViLLE platform participating in the JANUS project

The ViLLE platform is created to perform learning analytics. In the Analytics view, you can take a closer look at the performance of your students. The top bar shows the course you are looking at. Below that, you can select a specific lesson or all lessons, and either single student or all students' statistics. By default, ViLLE displays a view of all students in the last lesson taken. The upper frame shows the average scores of the students for that lesson. The accuracy indicates how accurately the students knew the correct answer to the task. The average time spent is in the format hours:minutes:seconds (**Figure 28**).

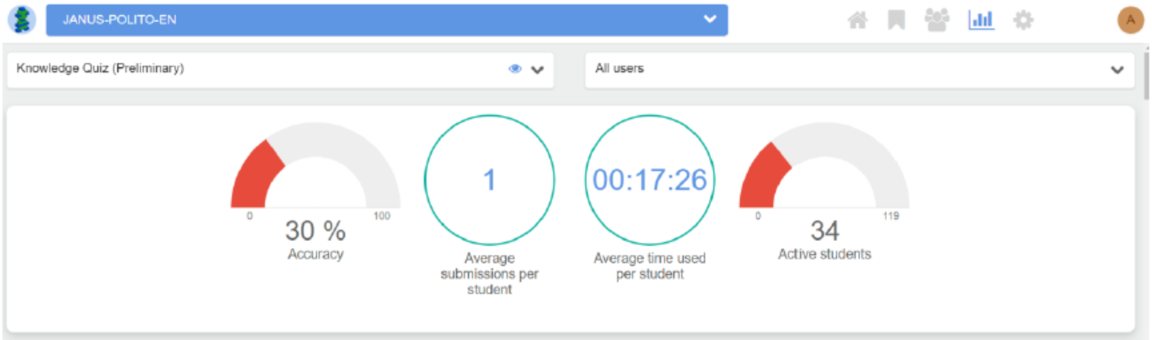

Figure 28 - Example dashboard from the ViLLE platform

Under the Lesson progress heading, you will find the results for each student for the selected lesson (**Figure 29**). You can adjust the width of the columns using the vertical lines in the title bar. Clicking on the column header will sort the table by the selected column.

From this table you can easily see who has already reached the minimum target for the lesson and received a bronze trophy. An asterisk after the trophy indicates that the student has been assigned a downward-differentiating warm-up task (white asterisk) or an upward-differentiating bonus task (black asterisk).

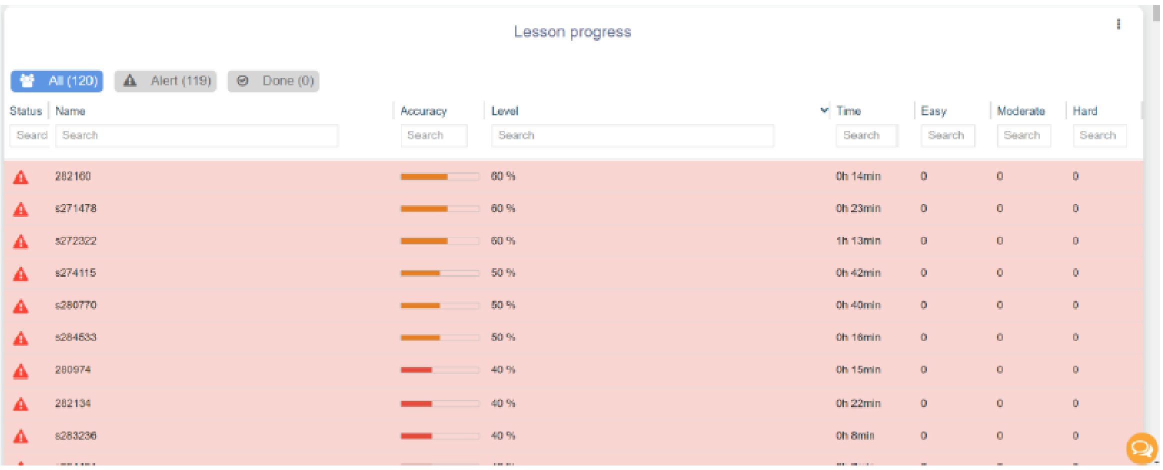

Figure 29 - View on the basic results obtained from students

The Student Effort graph shows the score of students in relation to time (**Figure 30**). The graph gives you a quick overview of the students in your class. At the bottom right are students who manage to accumulate a lot of points in a relatively short time. At the top right, you will find students who are very hard-working but have a slower rate of decline.

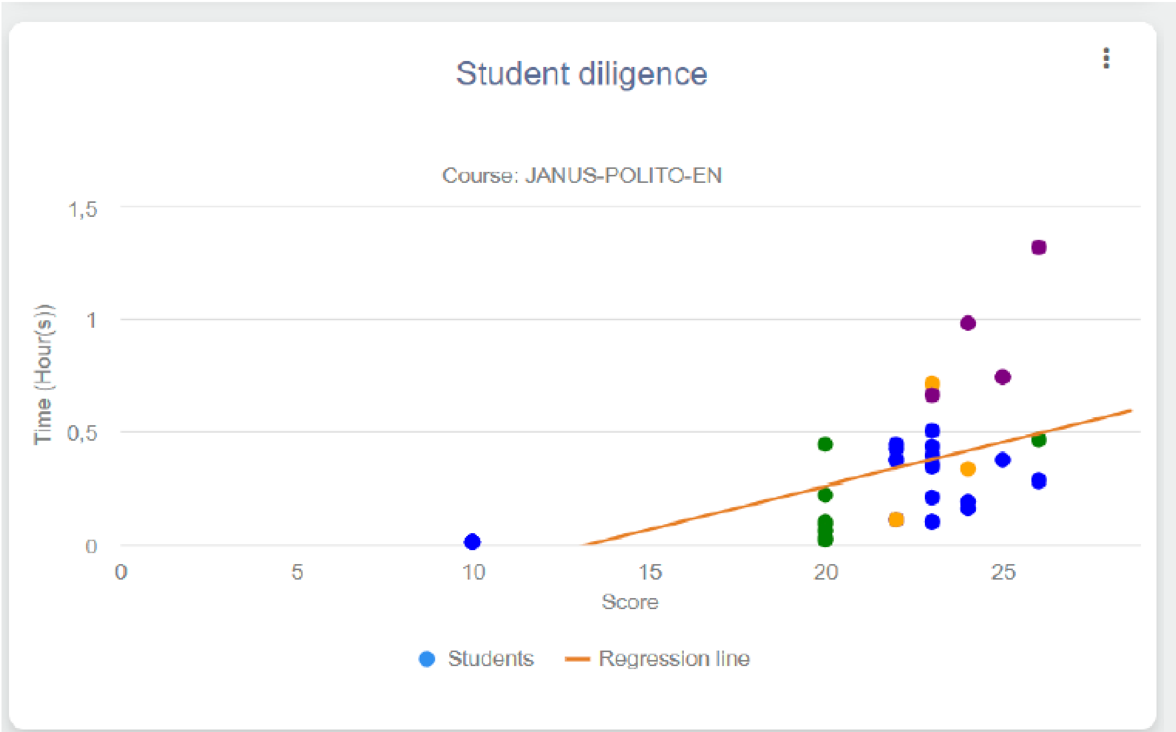

Figure 30 - Example of the results obtained from students in relation to time

The Statistics from a lesson graph collects also information on all the tasks in a lesson. The blue bar indicates the average accuracy of the students on that task.

The accuracy is calculated from all the student's returns for one task. The red graph shows the average time spent on the task. The yellow graph shows the number of times a student has attempted the task.

You can view your students' homework behaviour using a timeline. The timeline shows the number of returns at different times. The example below shows the time used for the whole course. Generally, high spikes on the graph indicate assignments completed by the whole class in class (**Figure 31**).

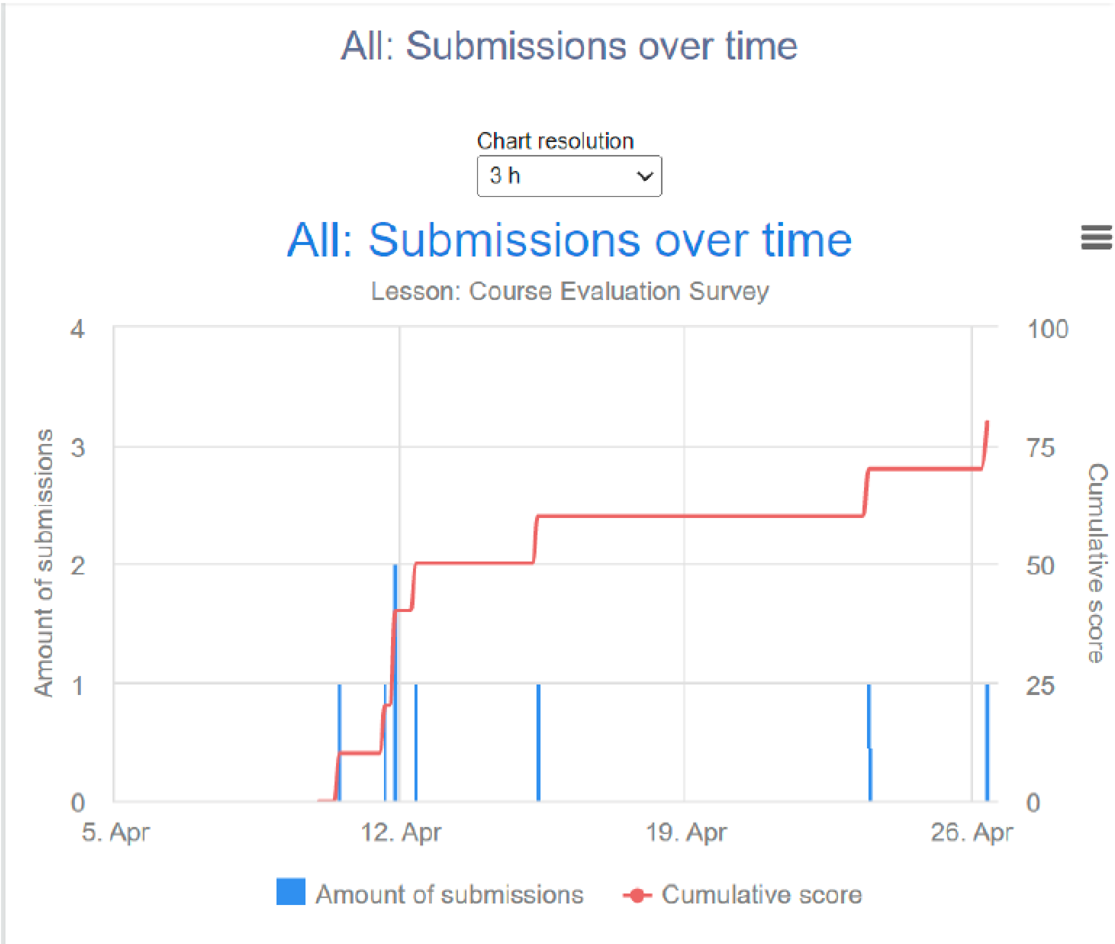

Figure 31 - Timeline of the student's homework behavior

5. Example of the intervention plan for teachers

What should the intervention plan for students look like in terms of robotic education? Therefore, first of all, the teachers should introduce the project objective during the lecture. Show students what has been created in terms of the JANUS Project and then locate them in the structure of it. Besides the description given during lectures and at some point, laboratories, students should also obtain the instruction from the teacher regarding the plan of the research. Below is an example of it.

Example of the information to be given to students are presented below:

Information

A few words on the intervention

The Blended Learning Robotics Education project aims at extending the educational activities you usually perform in the physical laboratories in a Virtual Reality environment. Within the virtual laboratory, you can 'interact' with robotic equipment while assessing your knowledge. In relation to the Virtual Reality tool, we are using a Learning Management System (LMS) named 'ViLLE'. The LMS is used primarily for research purposes (e.g. collection of demographic data, opinion surveys, and knowledge evaluation quizzes). Both the Virtual Reality (VR) experience and the LMS can be accessed from anywhere and at any time using your preferred browser (e.g. Chrome, Firefox) and the credentials provided below. According to your schedule, the intervention is expected to start on XX-XX-XXXX. For this reason, I kindly ask you to engage with the preface (pre-intervention) activities as soon as possible.

Please Note:

Your data are fully protected under the General Data Protection Regulation (GDPR).

- Researchers who will analyse/interpret the primary data will receive anonymised datasets.

Any data collected during the pilot case study will be utilised purely for the needs of the JANUS project.

- Your responses, both in the Virtual Reality environment and in the Learning Management System, will not be connected to your university performance (e.g. transcript).

You have the right to withdraw at any point without any consequences.

Pre-intervention stage – Week 1 [1 day]

Activity 1: Please login to ViLLE (https://ville.utu.fi/#!login). Under the Lessons section you will see a numbered list. Please fill in your demographic information and submit the form.

Activity 2: If you have completed the first step successfully, the Preliminary Survey task should now be open. Please fill in the corresponding survey regarding your prior educational experience with Virtual Reality solutions.

Activity 3: The final task concerns a brief knowledge quiz to help us assess your current knowledge level. Please, fill in the Preliminary Knowledge Quiz and submit your responses at the end.

As long as you have completed the aforementioned steps you can logout from ViLLE.

Intervention stage – Week 2 [7 days]

The teachers in charge will go through their teaching routine (e.g. delivery of lectures, visits to the laboratories). At this point you will receive additional information about the Virtual Reality education tool. To access the VR experiences please use the following link: https://rzeszow-lab.herokuapp.com/html/login.html

Activity 4: In line with your lecturers' instructions, you can start utilising the Virtual Reality educational tool. Please, go through the experience at least one time. You are, of course, welcome to revisit the experience for as many times as you wish within the proposed time-frame (minimum 1 week).

Post-intervention stage – Week 3 [1 day]

Following completion of the teaching-and-learning activities (including the ones that have taken place within the VR platform) we would like to reassess your knowledge acquisition. To achieve this goal, please login to ViLLE (https://ville.utu.fi/#!login) and undertake the second Knowledge Quiz (Conclusive) as well as the VR experience opinion survey (Conclusive Survey).

As long as you have completed all the aforementioned tasks you can logout from ViLLE.

The login credentials to access both the LMS and the VR experience are as follows:

Username: januspilots

Password: janus12345

6. Summary

Virtual reality is used to makes the educational process of students by providing them with an immersive and interactive environment that enriches the experience. VR can be used to simulate real-world scenarios, allowing students in particular to experiment and explore the capabilities of research apparatus in a safe and controlled environment. There are a number of ways to integrate virtual reality into various applications. We can use VR, for example, to simulate industrial design and manufacturing processes, where VR can be used to simulate factory layouts, assembly lines, and machine interfaces, reducing the need for expensive physical mockups. VR integration can also take place for training and simulation, where VR can be used to train people for various jobs and tasks. The topic addressed in the project described here was the integration of VR for educational purposes for selected robotics courses.

Robotics is a wide-ranging field of knowledge that includes the department of robot programming, operation, motion kinematics, and maintenance. All of these are linked by system safety. In an enclosed laboratory, the dynamics of the robot's movements can cause danger to the participants of the classes. Therefore, safety issues are a cornerstone that applies to virtually all courses that involve the presence of a robot. The method of implementing virtual reality for teaching robotics developed in this work touches on this area, among others.

Undoubtedly, the JANUS project allows students to gain high-quality knowledge without attending real-world classes. Especially this kind of application can be helpful as a supportive material for students to actually get to know with, e.g. some safety issues or as a full replacement of the classes in case some difficulties and circumstances that now allow to perform real-world classes.

The methodology developed in this handbook for dealing with the development, implementation, testing, and evaluation stages of student robotics can be helpful for developing further courses for other case studies.

Annexes

Annex 1 - Theoretical Framework and Conceptual Framework.

Annex 2 - Didactic content. Intended Learning Outcomes (ILO). Teaching and Learning Activities (TLA). Assessment Tasks (AT).

Annex 3 - Development of the VR platform and Educational Scenario (3D Content).

Annex 4 - Pilot of the use case. Case Study Monitoring. Continues Data collections from use case.

Annex 5 - ViLLE – The Collaborative Education Tool. Teacher Guide.

Annex 6 - Backend API & Server Configuration.

Annex 7 - Unit Testing.

Annex 8 - Specification of the research plan and the data collection instruments.

Annex 9 - Analysis of the primary data and visualisation of the outcomes.

Annex 10 - Framework for Virtual Reality Platform.

Annex 11 - Integration of Assessment. Teaching-learning Tool.

Annex 12 - Training Sessions.

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Co-funded by the
Erasmus+ Programme
of the European Union

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