



Enhancing Inclusive Education for Young Students with Special Needs through Mixed Reality: Exploring the Potential of CNC Milling Machine Application

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Abstract. Mixed Reality (MR) is one of the major technology trends right now, and it is going to increase much more in the future. This term includes different technologies that range from Augmented Reality (AR) to immersive Virtual Reality (VR). The main characteristic of AR is the possibility to see and interact with virtual objects while always being able to see the surrounding real world thanks to a dedicated device. This technology allows a new way of interaction, communication, and productivity. The aim of this paper is the development of an MR application for the Charly4U CNC milling machine that helps students with special needs to work and interact with the machine safely. Three configurations have been developed and tested: a desktop version running on a PC, an Android tablet-based version, and a solution running on the Microsoft HoloLens device.

Keywords: Virtual Reality, Training, Special Education, Neurodevelopmental Disorders, Down Syndrome, Autism.

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1 INTRODUCTION

In recent years, many people have encountered the terms Virtual Reality (VR) or Augmented Reality (AR) at least once, particularly within the educational environment. These technologies were first defined in 1994 when Paul Milgram and Fumio Kishino published "A Taxonomy of Mixed Reality Visual Displays." In this work, they introduced the concept of the reality-virtuality continuum and the term mixed reality (MR) to encompass all these technologies [13]. Over time, these technologies have gained popularity in universities. Students can utilize head-mounted displays for VR or optical see-through headsets for AR. With these technologies, they can explore entirely new worlds and develop innovative applications for educational purposes.

1.1 Mixed Reality in Education

One of the most important aspects of this work is its educational focus. The main idea behind this project is using innovative technologies like AR and VR to enhance the learning process, especially for engineering students. A century ago, Dewey emphasized the value of hands-on experience for understanding procedures, tasks, or activities [11]. This is particularly true for laboratory activities involving specialized machines and tools. Students must learn how to operate a machine and follow the necessary steps to mitigate risks for both the operator and the machine. However, students often face difficulties working with machines or fear causing damage, necessitating a supervisor, professor, or technician to teach them the detailed procedures for working with a specific machine.

Two primary limitations exist in today's learning procedures for complex mechanical tools. The first concerns the availability of the machines themselves. For instance, turning lathes or milling machines may not always be present in university laboratories or accessible to students. In these cases, students learn the machine's functions and processes through lectures or by reading books and user manuals. Nevertheless, this traditional approach has significant drawbacks compared to using interactive tools or practicing on an actual machine. The second limitation relates to the constant presence of skilled operators during machine use. These operators must teach students the processes and supervise the machine's operation, which complicates the learning process. While the physical presence of simple machines might not be essential, working directly on a complex machine can significantly improve the learning experience.

AR and VR technologies can offer alternative solutions that are both time and cost-effective. If learning requires a real machine to enhance technical concept comprehension, a technician's presence near the machine is also necessary. This incurs high costs as the skilled specialist must continuously monitor students' activities in the working environment.

Fortunately, MR technologies can address these problems. AR and VR enable undergraduates to access a graphical user interface containing all necessary models in a safe environment, eliminating the need for a technician or professor. The application can demonstrate and explain the technological procedures, providing an effective and efficient learning experience.

The literature reveals that the use of AR in education opens up new learning possibilities [18]. For example, teaching astronomy can be transformed by using AR tiles, virtual 3D modeling packages, web cameras, projectors, and whiteboards, surpassing traditional book-based methods. AR can visualize abstract concepts like airflow, magnetic fields, and molecules, and it can be used to create engaging AR games. In one example, students with Android tablets collected data on simulated radiation values on their campus, hypothetically located near a nuclear power plant. In [15], the benefits of using AR to visualize abstract concepts and phenomena otherwise imperceptible to human eyes are demonstrated. From these examples, it becomes clear that AR enables (i) 3D learning content, (ii) collaborative learning, (iii) learners' sense of presence, immediacy, and immersion, (iv) visualizing the invisible, and (v) bridging formal and informal learning.

AR can also enhance students' practical skills, which are difficult to acquire through traditional learning methods. AR provides a new dimension to learning, increasing students' interest in a topic by immersing them directly in the subject matter and improving spatial and psycho-motor cognitive skills. Matt Bower et al. [7] identified several pedagogical aspects that AR can support during their research: (1) constructivist learning, as AR increases students' engagement with the topic and deepens their understanding of concepts, (2) situated learning, as AR brings real-world experiences into the classroom, (3) game-based learning, where game interfaces facilitate learning specific topics, as shown in [18], and (4) inquiry-based learning, which involves electronically gathering data for future analysis. The advantages of AR in the educational setting are clearly outlined in [2, 15], including learning outcomes, pedagogical contributions, interaction, and more.

Brian Boyles [8] explains that these new technologies enable the simulation of dangerous and rare situations, allowing students to learn safely. For instance, he proposes a medical application where inexperienced surgeons can practice without harming patients, and another example demonstrates safely learning to use machine tools.

There are, however, some drawbacks to using AR and VR in education. As noted in [18], schools and teachers in the early stages of transition may resist the technology, fearing a diminished role for teachers in the learning process. While the learning process and the roles of both students and teachers are changing, this does not render teachers obsolete. Instead, as explained in [8], the role of professors is shifting from knowledge deliverers to facilitators, helping students explore and learn with new technologies like tutors or coaches. Concurrently, the educational process is also changing for students, empowering them to take center stage in the learning activity and become more active in the process due to the interactivity of the applications [15].

2 CASE STUDY: MR FOR LEARNING CNC MILLING FOR STUDENTS WITH SPECIAL NEEDS

2.1 Mixed Reality in Industrial Environment

The literature reflects several research activities focused on the educational aspect of the industrial field. However, most of these efforts are geared toward users such as workers, expert personnel, and technicians rather than students. For example, Vieira et al. [17] proposed a VR model for a green ironmaking industrial unit, essentially a typical charcoal mini-blast furnace (CMBF). Minoufekr et al [14] proposed a communication framework to simulate CNC machine production through MR using the Microsoft HoloLens. In their process, the workpiece meant for creation on the computerized numerical control (CNC) machine is designed with Computer Aided Design (CAD) software, then converted into working steps and toolpath in a CAM environment. The resulting g-code contains all the necessary information for the machine to process the workpiece. Chardonnet et al [10] proposed an AR application to assist users in handling CNC machine tools. The number of applications targeted specifically at students is even more limited. Antonietti et al [3] described a VR environment with hypermedia designed to help undergraduates understand the structure and functioning of a turning lathe. This application includes VR and hypermedia environments that clarify the sequence of operations to be carried out before beginning the actual machining process. In [12], a virtual training laboratory offers a case study of machining and measuring a spherical mold by interacting with two virtual machines. Vergara et al. [16] developed an interactive virtual platform to enhance self-learning through a virtual materials laboratory, which includes an interactive compression test machine. This paper aims to progress further in this direction, presenting an MR application for educational purposes focusing on a CNC machine for milling operations specifically designed for students with special needs.

2.2 Aspoc Association

Aspoc is an Italian association founded in 2004 by a group of parents with children affected by neurodevelopmental disorders (e.g., Down syndrome, autism, and intellectual disability). As an inclusive space, the association works to develop learning contexts that improve inclusion in schools and society in general. The mediated learning process emphasizes the crucial roles played by educators, rehabilitation experts, siblings, healthcare workers, and institutions. Aspoc, which stands for Association for the Development of Cognitive Potential in Italian, collaborates closely with local services and facilities. Relying on current scientific theories of structural cognitive modifiability, Aspoc believes in the importance of context, processes, and the quality of mediated learning for individual development. One of their primary goals is to establish a cultural and social context that supports individuals with disabilities and their families. Aspoc's project is structured around three areas where individuals with Special Educational Needs (SEN) interact in daily life: family, school, and health. ASPOC College, an initiative of the association, targets students aged 19 and older to further develop their manual skills and cognitive enhancement in preparation for future work experiences. Utilizing a Computing Module, the project aims to define best practices for the training path suitable for these students, focusing not only on VR and rehabilitation topics but also employing a pedagogical approach to identify the optimal set of rehabilitation activities for cognitive enhancement. In this context, the Virtual Reality and Augmented Reality Laboratory at Politecnico di Milano, Lecco campus, offers weekly lessons to Aspoc's teenage students,

demonstrating how technology can improve cognitive and motor skills for individuals with special needs. Technologies such as CAD/CAM, 3D printing, augmented reality, and virtual reality are employed in these scenarios. Consequently, it was decided to develop and test the proposed MR application with the Aspoc team students, conducting these activities on a weekly basis.

3 MR APPLICATION

3.1 Technical Specification

The main concept of the application is to educate and guide students throughout their work on a specific CNC machine. The Charly4U CNC milling device from Mecanumeric, shown in Figure 1, has been chosen for this case study. The figure also includes some of the tools that students can utilize to perform various operations [1].



Figure 1: The Charly4U CNC milling machine and some of its associated tools

The Charly4U machine comes in two configurations. The default layout uses a 3-axis system, with the spindle moving horizontally (x direction) and vertically (z direction), while the base can slide (y direction). The second layout allows for a four-axis configuration, where in addition to the previous three movements, a second spindle can rotate the workpiece around its axis, introducing a fourth direction of movement.

Given this design, the overall MR application is split into two parts (and menus), depending on whether the fourth axis is used. However, the general technical data remain largely the same. The application guides users through all the steps necessary to set up and operate the machine from start to finish. These steps include:

- Axes movements: This set of animations help users understand the axis motion and the corresponding software commands to control it.
- Power on: Details the process required to turn on the CNC machine and connect it with the corresponding software.
- Emergency stop: Explains how users can stop the machine operation.
- Air-lubricant flow: Animations showing the three possible settings for this control; switched off, air only, or air-lubricant flow.
- Milling tools insertions: A series of animations explaining the steps to correctly position the end mill, the holder, and the ring nub (applicable for both three-axis and four-axis configurations).

- Milling tools removal: Applicable for both the three-axis and four-axis configurations.
- Workpiece insertion: Animations demonstrating the process required to correctly position and secure the workpiece (applicable for both three-axis and four-axis configurations).
- Workpiece removal: Applicable for both the three-axis and four-axis configurations.
- 360 degree overview.
- Stock box point: This process must be followed each time a new workpiece is positioned on the base. The outcome of this process provides the machine with the coordinates of the workpiece, which will be used during the milling process.
- Tool calibration point: This step must be done each time a tool is replaced. It allows the machine to accurately identify the position and dimensions of the end mill.

3.2 Menu and Scenes

The digital model of the Charly4U CNC milling device was created using parametric CAD software. This software generated 3D models, parametric assemblies, and crucial animations that were later used in the Unity software. This method makes it easier to develop different versions of the applications, such as for desktop, mobile, and HoloLens.

The overall application was developed using the game engine software Unity, while the 3D models representing the twin of the Charly4U milling machine and its tools were designed using the CAD software Autodesk Inventor. This paper details the application designed for three different target devices: desktop PC, Android tablet, and Microsoft HoloLens device. Although the interaction mechanisms vary significantly between these technologies, the overall structure of the application and the technical concepts described are consistent.

The initial scene presents the project name and its developing partners via a graphical interface. The following scene provides technical data about the Charly4U CNC machine, as shown in Figure 2 (a). This information includes the machine's and table's dimensions, the axes strokes, the maximum speed, the resolution, etc. Additional details about the manufacturing company are displayed on the left side. A link to the company's website is also provided under the company logo for easy access to more information. Finally, on the right side, there is a picture of the machine and a list of its optional features. This scene serves to give a brief presentation about the CNC machine in terms of its characteristics, dimensions, and performances. Following this introduction, clicking on the "next" button begins the core of the application with the 'New Machine Setup' scene (Figure 2 (b)). In this scene, the user has three different buttons to choose from: 'Before Starting', '3 Axes Layout', '4 Axes Layout'. Clicking the 'Before Starting' button, the initial procedure to power on the machine and to link it to the computer-based software is shown. The '3 Axes Layout' button opens a sub-menu (Figure 2 (c)) with all the procedures listed before in the three-axis possible configurations of the milling machine. Every orange button opens a new scene (Figures 2 (d, e)) with the task selected shown with a series of multiple animations that illustrate and explain the process plus the different tools involved in the task. Similarly, the '4 Axes Layout' button presents the menu (Figure 2 (f)) and the animations in the 4-axis configuration (Figure 2 (g, h)). In both layouts, two yellow buttons are present, which respectively allow the user to explore and manipulate the machine in a 3D view or to automatically play the entire procedure with all the steps.

4 DESKTOP AND ANDROID TABLET VERSION

The initial version of the application was developed for a desktop Windows PC. The primary objective of this initial version was to familiarize students with the Charly4U CNC machine under the guidance of an educator before they physically interacted with it. This version can be controlled by the teacher and demonstrated to the entire class using a video projector (Figure 4 (a)).

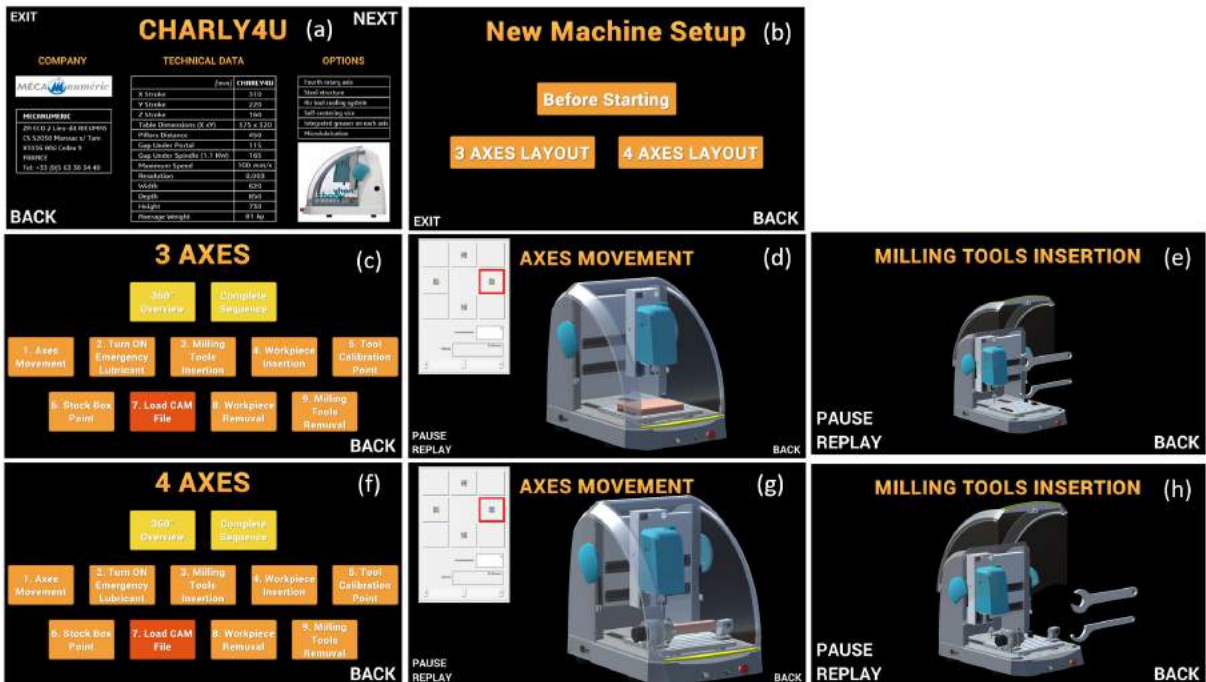


Figure 2: Application's scenes. (a) Scene featuring the machine's technical data, (b) main menu in the machine setup. (c) Selection example for the three-axis configuration, (d) 3D view of axes movement, and (e) insertion of milling tools in . (f) Menu for the four-axis configuration selection, (g) 3D view of axes movement, and (h) insertion of milling tools in four-axis configurations.

Software Unity was used to create all the 3D animations for illustrating the tasks. It enables the modification of objects' characteristics (such as position, rotation, scale, color, etc.) with a timeline-based approach. This method allows the synchronization and combination of different actions to present a more comprehensive description of a process. An example of this approach is illustrated in Figure 3, which shows the task of inserting milling tools. In this case, the end mill, the holder, and the ring nuts are placed inside the spindle support using a regular wrench and a C-shaped one. As the wrench rotates around the spindle support, the milling tools move along the z-axis, facilitated by the C-shape wrench that prevents the ring nut from rotating. Figure 3 (b) showcases the specific coordinates and rotation angles of every component at that selected point/frame in time. To illustrate the concepts to students, animations of the 3D parts of the milling machine are combined with animated graphical user interfaces (GUIs). Unity allows these to be generated in the same manner and combined to create the final overall animation.

The second version of the application was developed Android tablets. This version was designed to enable students to independently learn the tasks that can be carried out with the Charly4U machine (Figure 4 (b)). The primary distinction between this version and the desktop version lies in the human-computer interaction mechanism. While the desktop version requires peripherals like a mouse and keyboard to make selections, the tablet version employs a touch input system. This new mechanism, once integrated into the application, not only converts the selection action from a physical button to a touch click but adds numerous possibilities to students. It allows the students to use their fingers to move, zoom in/out, rotate, spawn, destroy, press, and hold a 3D object. In the MR application, this translates into the possibility for students to examine the 3D models or to move, rotate, and translate the milling machine using touch gestures. This version can be

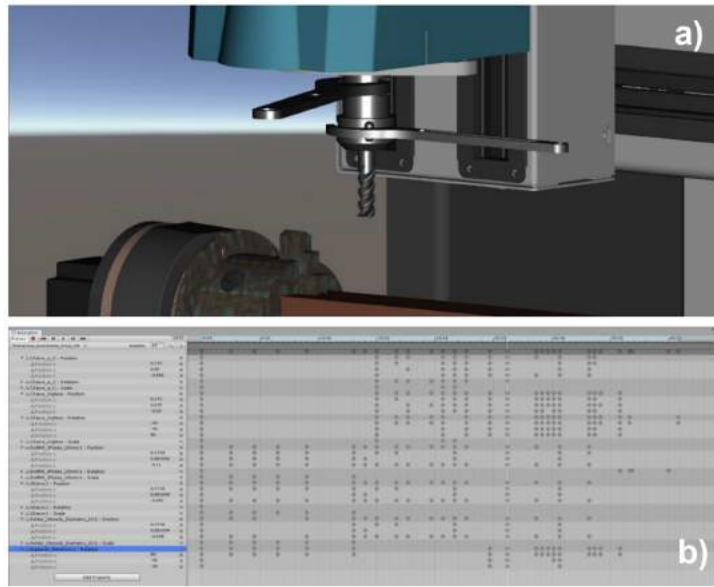


Figure 3: (a) Scene view of milling tool insertion, and (b) Animation panel displaying the coordinates and rotation angles of the objects involved in the selected frame

installed on multiple mobile devices by generating the .apk file and uploading the installer on Android tablets.

5 HOLOLENS R1 VERSION

The final version of the application was specifically designed for use with the Microsoft HoloLens R1 device. This device enables mixed reality, wherein 3D virtual content overlays the actual environment, allowing students to interact seamlessly with both realities.

The interaction mechanism for this device relies on a completely different approach compared to the previous versions. Users need to direct their gaze toward an element using head movement and select it by using specific gestures. This can be observed in some photographs taken during the evaluation phase with Asproc students, as shown in Figure 4 (c, d, e).

The HoloLens device is capable of recognizing certain gesture interactions through sensors embedded at both extremities. When the user performs an open hand gesture, the main menu is activated. Subsequently, the user can select the icon to activate the Charly4U application using a specific hand gesture - a finger tap gesture (analogous to a mouse click).

In order to familiarize students with this method, a couple of scenes titled 'Before Starting' and '360 Overview' have been implemented. The first presents a three-dimensional GUI, similar to the one presented in Figure 2 (a), allowing the students to get used to pointing and clicking to select GUI buttons. The second, on the other hand, allows students to visualize, explore, and place the 3D model of the Charly4U machine as though it were physically present in their real world. After selecting the 3D model of the Charly4U machine by the finger tap gesture, a blue bounding box appears around the object to indicate the possibility of moving it (Figure 5 (a)). It is relevant to point out that a HoloLens' user sees the real environment in place of the areas with the black background in Figures 5 (a, b).

Once students have practiced gesture interaction, they can proceed to the '3Axes Movement' scene. Here, the application explains the commands the user needs to press to move the axes. Following this, all remaining

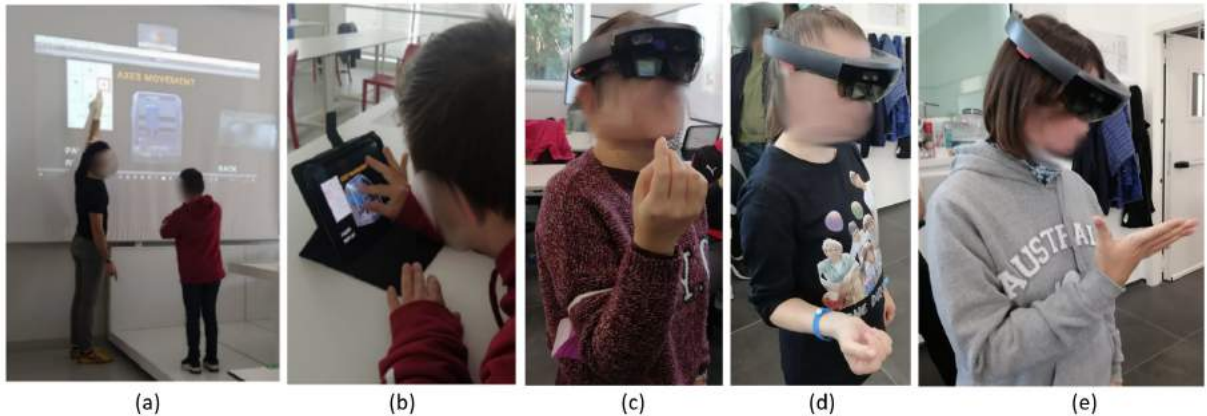


Figure 4: (a) Initial interaction with the desktop application via a projector, (b) An Aspsc student independently exploring the application on a tablet, and (c, d, e) the application being utilized through the Microsoft HoloLens R1.

scenes are used to teach the procedures necessary to set up the CNC: milling tools and workpiece insertion, stock box point and tool calibration point loading the .iso file with the machining instructions, and workpiece and milling tool removal. Each scene is structured as follows: at the top, the name of the current procedure is displayed. Just below, two blue buttons allow the user to navigate to the next or the previous operation. On the right side of the user's Field of View (FoV), two more buttons are available, namely, the 'Next Step' for the current operation and the 'Pause Animation' button. Below these, all 3D models and GUIs are displayed (Figure 5 (b)). An essential aspect to consider when using the Microsoft HoloLens device was the ability to allow a teacher or a tutor to always observe the virtual environment the student was interacting with. This feature is crucial for providing assistance to the student in case of difficulties, particularly with individuals with special needs. As depicted in Figure 5 (c), the virtual environment and actions performed by the student wearing the HoloLens could be streamed to a desktop PC and projected onto a screen for the entire classroom to view.



Figure 5: (a) 360 Overview scene with blue lines representing the bounding box, (b) 3 Axes Movement scene, and (c) Training session with Aspsc Student.

6 PILOT STUDY: USABILITY TEST

The usability of any newly developed product, system, application, or software should always be evaluated. Understanding the response of users, especially those with special needs or characteristics that differentiate them from the majority of users, is crucial. It is nearly impossible to gauge the usability of a system or tool without considering the context in which it is used and the corresponding users. In essence, it is impractical to compare and classify the usability of different systems that cater to different contexts or users, as they essentially have nothing in common. Conversely, features, layouts, or procedures that are effective in a specific environment may not always be suitable in a different context. Generally, usability measures can be categorized into effectiveness (the ability to complete tasks using the system and the corresponding output quality), efficiency (the amount of resources used in performing the task), and satisfaction (the users' subjective reaction to using the system).

Teenagers with neurodevelopmental disorders may struggle with hand movements, making applications that rely on touch and gesture inputs particularly valuable as they leverage technology to assist these students. However, existing literature suggests that the quality of hand-gesture interactions during cognitive exercises can lead to positive outcomes [4, 5]. Therefore, conducting a usability test is important to understand the students' perceptions of the application. To that end, the Desktop version, Android tablet version, and the Microsoft HoloLens R1 version of the developed application were tested by 13 students from ASPOC College.

6.1 System Usability Scale - SUS

The System Usability Scale (SUS) proposed by John Brooke in 1986 [9] was utilized for this purpose. This tool comprises a 10-item questionnaire with five response options, ranging from 'strongly agree' to 'strongly disagree'. It facilitates the evaluation of a broad array of products and services, including applications.

In order to ensure optimal learning outcomes for the Aspoc students, the application was initially introduced with the assistance of a projector. This guided students in understanding all the crucial aspects of the process. Subsequently, participants had the opportunity to individually interact with the computer version, tablet version, and HoloLens version of the application.

Some Aspoc students found it challenging to associate their answers with the traditional scale of the SUS, which employs a 5-point Likert Scale ranging from 'strongly disagree' to 'strongly agree'. To simplify this, the scale was adjusted to utilize a 5-smiley representation, as depicted in Figure 6. Moreover, the questionnaire was orally administered by the educators to the students. This approach served a dual purpose; it helped clarify any ambiguous questions and enabled the clear identification of the students' responses on the scale. Spontaneous comments made during and after the interaction with the devices were also taken into consideration to gain a more comprehensive understanding of their experience.

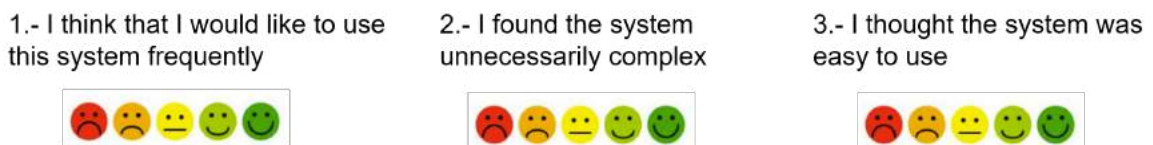


Figure 6: Aspoc SUS Questionnaire.

To obtain the final score as a number out of 100, the 5-smiley scale has been converted to the classical numerical scale from 1 to 5. Then, the answers have been normalized: for each of the odd-numbered questions, 1 has been subtracted from the score, and for each of the even-numbered questions, their value has been subtracted from 5. These values have been added up and multiplied by 2.5.

6.2 Results and Discussion

After interacting with all three versions of the application, each of the 13 students completed the SUS questionnaires with guidance from their educators. Following this, the SUS scores were compiled and compared to determine the most effective solution. The mean and standard deviation values, based on the normalized scores of the three versions, are summarized in Table 1, Table 2, and Table 3. The desktop application received an average score of 69 ± 8.4 out of 100. The Android-based application scored an average of 85.2 ± 17.8 out of 100. While the Microsoft HoloLens version received a score of 70 ± 17.5 out of 100.

Table 1: SUS questionnaire results for the desktop-based application had a mean score of 69/100. The mean values ranged from 0 to 4 and negatively worded items were normalized.

	Statement	Likert Scale (1:5)	Normal Mean (0:4)	Std. Dev.
1	I think that I would like to use this system frequently	3.33	2.33	0.60
2	I found the system unnecessarily complex	1.85	3.15	0.73
3	I thought the system was easy to use	3.77	2.77	0.80
4	I think that I would need the support of a technical person to be able to use this system	2.44	2.56	0.83
5	I found the various functions in this system were well integrated	3.77	2.77	0.59
6	I thought there was too much inconsistency in this system	1.95	3.05	0.62
7	I would imagine that most people would learn to use this system very quickly	3.98	2.98	0.94
8	I found the system very cumbersome to use	2.28	2.72	0.92
9	I felt very confident using the system	3.44	2.44	0.70
10	I needed to learn a lot of things before I could get going with this system	2.25	2.75	0.83
	Total (Sum*2.5)		69.00	8.4

Table 2: SUS questionnaire results for Android-based application. Mean values range from 0 to 4, and negatively worded items have been normalized. The system obtains 85.2 / 100

	Statement	Likert Scale (1:5)	Normal Mean (0:4)	Std. Dev.
1	I think that I would like to use this system frequently	4.45	3.45	0.93
2	I found the system unnecessarily complex	2.00	3.00	1.73
3	I thought the system was easy to use	4.73	3.73	0.65
4	I think that I would need the support of a technical person to be able to use this system	2.00	3.00	1.34
5	I found the various functions in this system were well integrated	4.64	3.64	0.50
6	I thought there was too much inconsistency in this system	1.45	3.55	0.69
7	I would imagine that most people would learn to use this system very quickly	4.64	3.64	0.50
8	I found the system very cumbersome to use	1.91	3.09	1.45
9	I felt very confident using the system	4.73	3.73	0.47
10	I needed to learn a lot of things before I could get going with this system	1.73	3.27	1.10
	Total (Sum*2.5)		85.20	17.8

From the questionnaires and the comments during the activity, it emerged that this experience was very interesting for all the Aspoc students, as they were happily interested in the applications. All students were

Table 3: SUS questionnaire results for the HoloLens-based application had mean values ranging from 0 to 4, and negatively worded items were normalized. The system obtained a score of 70 out of 100.

	Statement	Likert Scale (1:5)	Normal Mean (0:4)	Std. Dev.
1	I think that I would like to use this system frequently	4.00	3.00	1.26
2	I found the system unnecessarily complex	2.45	2.55	1.44
3	I thought the system was easy to use	4.09	3.09	0.94
4	I think that I would need the support of a technical person to be able to use this system	3.27	1.73	1.42
5	I found the various functions in this system were well integrated	4.27	3.27	0.90
6	I thought there was too much inconsistency in this system	1.82	3.18	1.08
7	I would imagine that most people would learn to use this system very quickly	4.00	3.00	0.63
8	I found the system very cumbersome to use	2.36	2.64	1.29
9	I felt very confident using the system	3.82	2.82	1.08
10	I needed to learn a lot of things before I could get going with this system	2.27	2.73	0.79
	Total (Sum*2.5)		70.00	17.5

excited about the possibility of seeing and interacting with a virtual entity, which is not a common activity. On analyzing the data provided, it is possible to understand the differences in terms of usability among the three configurations.

The results show that the tablet configuration obtained the highest score in terms of usability. According to the indications of [6], this means that usability is considered excellent (see Figure 7). In the desktop application (Table 1), the interaction method was based on the keyboard and mouse. Some Aspoc students experienced difficulties in using the input devices of the desktop version. On the other hand, they felt more confident in using the touch input system of the Tablet version (Table 2). In fact, question number 9 is the one that gave the highest discrepancies between the two versions. In the normalized scores, the tablet version got 3.73/4, while the desktop one only got 2.44/4. This aspect can be explained, according to some of the students' tutors, in the majority of Aspoc students attend most of the courses using tablets or mobile phones. The knowledge of these devices can create a higher sense of confidence in technologies that exploit the touch

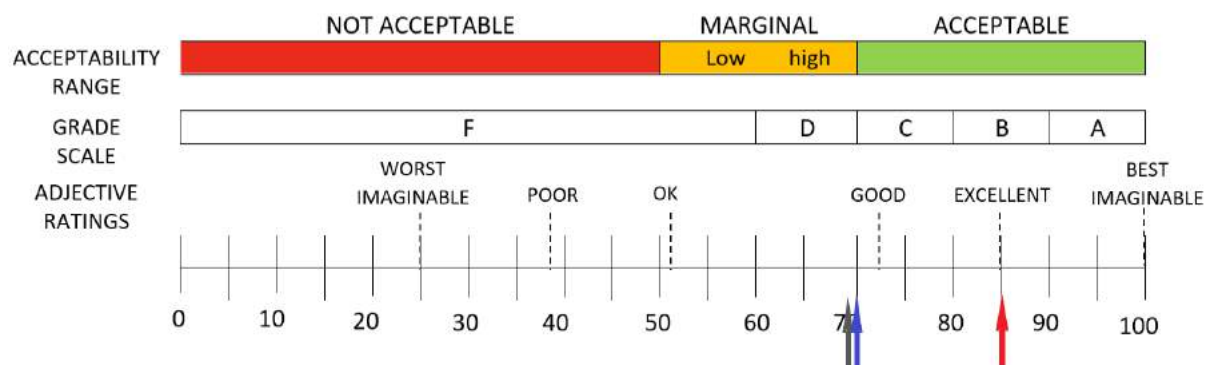


Figure 7: SUS results according to [6] for desktop (black arrow), tablet (red arrow), and HoloLens (blue arrow).

input modules compared to the others. In general, the usability of the desktop application was considered "almost okay" (see Figure 7), according to [6]. As we can see, the final score value is close to 68, and thus, it is also possible to conclude that the application has followed the usability standards or, at least, that the usability performances are similar to all of the ones present in the SUS database.

The Microsoft HoloLens version (Table 3) gained a usability evaluation of "almost good" [6] (see Figure 7). Furthermore, the results showed two main outcomes. The first is related to the high interest and curiosity that students expressed toward this version; question number 1, related to the willingness to use the application, had a normalized score of 3/4 compared to 2.33/4 of the desktop version. However, this value was lower than the one reached by the tablet version (3.45/4). This behavior was likely due to the interaction mechanism, as participants' comments reported. The second main outcome is that students found a similar complexity level in learning how to use the desktop and HoloLens versions (question number 10).

In particular, some of the participants had difficulties in visualizing the mixed reality models due to the limited field of view (FoV) of the HoloLens R1. Furthermore, during the evaluation, the headset was set with some common physical characteristics, such as the interpupillary distance (IPD). However, by customizing these parameters, these problems could have been reduced. Moreover, some of the participants had trouble with the interaction gestures, at least in the initial part of the test. This issue has been related to the novelty of the product, which was new to most of the participants. In fact, after a few minutes of training, most of them were able to correctly handle all the hand gestures. It is important to note that only some of the participants had this problem, while others did not encounter any major difficulties in using the application.

Both the tablet and HoloLens versions obtained a score higher than 68, performing better than the average results in the SUS database [6]. For the HoloLens version, the score was around the 50th percentile, and for the tablet configuration, just below the 90th percentile. Based on these data, it is possible to say that the results obtained were good in terms of usability.

7 CONCLUSION

This work presents an MR application to assist young students with special needs in the learning process of laboratory activity. The application has been designed using the Charly4U CNC milling machine as a case study. An active role in education can improve students' engagement and learning, and this is especially evident in laboratory activities involving specialized machines. Such activities, however, require a skilled supervisor with a physical machine available in order to allow students to learn and test the process. This paper aims to take a step forward in this regard, considering students with special needs who present neurodevelopmental disorders. The application has been designed in three different versions, each with a target device and interaction system: a desktop PC, an Android tablet, and a Microsoft HoloLens R1. A pilot study with 13 students with special needs from the ASPOC college was conducted, and all three versions of the application were tested and compared using the SUS questionnaire. All students showed enthusiasm and interest in the application. The tablet version scored highest in terms of usability and confidence. The limited field of view (FoV), combined with the novel gesture interaction mechanism of the HoloLens device, had a negative impact on the score and the high willingness to use the application. This aspect, however, could be limited by customizing the device settings to each student and including a training phase before the evaluation to let the students become accustomed to the gesture input. The desktop version obtained the lowest score in the SUS questionnaires due mostly to the numerous difficulties encountered in using the traditional mouse and keyboard input devices. Overall though, all three versions were rated as having acceptable usability, and it can be assumed that they are usable in a more structured way for teaching people with special needs. In the future, it would be interesting to make further evaluations to investigate other characteristics of the applications' versions, such as the level of engagement and the emotional state given by the interaction.

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