Virtual Reality in Education to Enable Active Learning and Hands-on Experience

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Abstract. Teaching technical contents related to product design and 3D modeling is a challenging task. Students enrolled in Master of Science courses often have different backgrounds and technical skills, due to their different educational paths at the bachelor's degree. From the student's perspective, one of the main difficulties concerns the definition of the 3D modeling procedure, understand technical drawings and figuring out the proper assembly sequence to get the final product. Over the years, some methods to fill these existing gaps have been experimented, such as tutoring and Massive Open Online Courses. Despite these passive approaches have been proven useful for students, digital technologies, such as Virtual Reality, can boost the implementation active learning sessions and hands-on experiences. In this paper, we present a Virtual Reality application for active learning developed to help students in the initial stage of the "Methods and tools for detailed design" course to acquire a set of lacking knowledge, which includes technical terminology related to mechanical parts and components, the ability to decompose mechanical systems into sub-parts, and to create a 3D model using a CAD tool given a 2D engineering drawing. To evaluate the effectiveness of the proposed approach, the application has been tested with a cohort of students with different backgrounds and knowledge about mechanical design and CAD.

Keywords: Virtual Reality, Virtual learning, Virtual Reality for education, Active learning, hands-on experience.
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1 INTRODUCTION

"Methods and tools for detailed design" is one of the subjects taught to students of the Master of Science (M.Sc) in Design & Engineering, at the School of Design, Politecnico di Milano. Students

enrolled in the M.Sc have different backgrounds and technical skills, due to their different educational paths at the bachelor degree level (usually product design, mechanical engineering, and materials engineering). A major challenge is teaching the principles of product detail design, 3D modelling, and technical documentation using CAD tools to such a diverse audience.

One of the main difficulties encountered by students at the beginning of the course concerns the definition of the 3D modeling procedure and deciding the approach for constructing geometries as a sequence of form features necessary to create the 3D model of an object starting from a given technical drawing. Another difficulty is figuring out a product and the components that compose it and learning the assembly sequence of the components to generate the final product.

Over the years, some methods have been experimented to provide basic principles and fill the existing gaps of some students so that they can catch up with the more knowledgeable students and subsequently start learning more complex contents. Some proven methods include books and technical handouts, short presentations, and Massive Open Online Courses (MOOCs). These learning materials explain concepts and provide examples or exercises through texts, 2D images, and some videos. For the students, this might involve simply reading or listening to a lecture or watching a video, without actively seeking to understand or remember the material being presented. In fact, these kinds of methods allow a passive approach to learning, where students receive information without actively engaging with it or attempting to understand it in depth. Besides, it often happens that students get distracted during reading or explanations, miss concepts, and sometimes get bored. Overall, passive learning may have little help for students to retain and understand the technical concepts, and students may be disengaged [21]. Passive learning can be contrasted with active learning, which involves actively engaging with the material and applying the knowledge being learned.

Hands-on experience can also be used to engage students more. Hands-on experience refers to learning through direct participation or experimentation, and is a way of learning by doing, rather than just observing or being told about something. Hands-on experience can be an effective way to learn new skills or concepts, as it allows students to apply what they have learned in a practical setting and see the results firsthand. It can also help them to better understand the subjects, as they are able to make connections between the theory and the practical application.

Digital technologies, and more specifically Virtual Reality (VR) technology, can be exploited in education to implement active learning sessions and hands-on experiences. VR learning is a form of education that utilizes VR technology to create immersive, interactive learning experiences. VR learning allows students to engage with and explore virtual environments, scenarios and simulations in a way that is both engaging and educational. It can be used to teach a variety of subjects, from new terminology in the field of mechanical engineering to assembly sequences of mechanical components. Overall, VR can play a unique role in addressing educational challenges and offers the possibility for learners to better learn and retain contents [11]. Besides, VR technology allows creating immersive experiences which are attractive for young students, who use 3D and VR technologies in their personal life. On the other hand, creating digital experiences that resemble physical hands-on experiences allow teachers to manage a high number of students without the need of having huge classrooms and provide the physical object under consideration. From this standpoint, this is especially handy when the object is bulky or expensive.

In this paper, we present a VR application for active learning developed to help students in the initial stage of the "Methods and tools for detailed design" course to acquire a set of lacking knowledge, which includes technical terminology related to mechanical parts and components, the ability to decompose mechanical systems into sub-parts, and to create a 3D model using a CAD tool given a 2D engineering drawing. To evaluate the effectiveness of the proposed approach, the application has been tested with a cohort of students with different backgrounds and knowledge about mechanical design and CAD.

2 RELATED WORKS

The use of digital technologies, and especially Augmented Reality (AR) and Virtual Reality (VR), has increased in recent years across many sectors. Educators are adopting these technologies at different academic levels to improve the learning experience of students [19].

Literature suggests that VR and AR in education and training are spreading [22] and can improve student outcomes. For example, in a March 2019 report, EdTech cites a study showing that students in a Mixed Reality (MR) biology classroom received higher scores than other students [28]. Furthermore, VR can help with memory retention and recall. EdTech reports on a recent study that shows an increase in retention of almost 9% for students who learned in an immersive environment such as VR.

Compared to traditional education tools, VR provides many advantages, such as cost savings and efficiency related to the less time required for memorizing information [23, 24]. Moreover, virtual class simulations can provide a safe environment for testing experiments that can otherwise be dangerous in real life [26].

Numerous studies are investigating the impact of using immersive visualization to teach scientific and technical concepts. VR has been shown to facilitate the visual understanding of complex concepts for students and reduce concepts misunderstanding. For instance, VR has been proven effective in helping students master a concept where visualization is a key element, such as in 3D vector and vector algebra [5]. VR is also widely used for education in the medical field. For example, immersive collaborative systems are used for nurse education [9], medical training [15, 18], and surgical programs [3].

More advanced concepts have also been given an attempt: in [25], traditional hands-on have been "augmented" with a MR application able to display the 3D model of a turbofan engine. The experimental results showed that the major benefit of using MR concerns the students' visualization ability. Given the ability of VR and AR to provide multimodal and multisensory information, some studies also compared VR and AR learning outcomes when multiple sources of information (e.g., visual and auditory) are provided. In [13], a comparison between smartphone-based VR and AR in the context of information retention has been performed: preliminary results showed that VR seems to be more effective than AR when conveying visual-related information. It may be that being in a fully virtual world, the user focuses more on the mediated environment.

Using Head Mounted Displays (HDMs) for immersive VR experiences seems useful for cognitive skill acquisition (remembering and understanding spatial/visual information), psychomotor skills (head movement, visual exploration), and affective skills (emotional control and response to stressful situations) [13]. When using AR, the cognitive and physiological response to the mediated environment seems to be weaker, allowing the user to pay more attention to other sources of information (e.g., auditory). Moro et al. [20] compared VR, AR or tablet-based simulations when teaching medical science and found that all of them enhance learning and no significant difference is observed among them. In addition, many studies present comparisons between traditional learning methods and VR learning applications. For instance, an experiment reported by [1] addressed traditional book learning, VR learning and video to test and compare the knowledge acquired by students. The results showed that students belonging to the Virtual Reality group showed better recall of information and more positive emotions than the other groups. Another explorative research work [4] reported that VR presents an improved learning experience when compared to other traditional learning methods, such as video.

Given the potential of VR, this technology is often used to replace more traditional technological means. For example, in a Chinese university class, the projector was replaced with HMDs to increase the motivation and control of the students over the lesson [6]. Moreover, both VR and AR can be very effective in presenting students with tangible simulations that can be animated or interactive. Thanks to the three-dimensional reconstruction of environments and objects, it is possible to visualize complex elements from many points of view and interact with different parts of a system to gain a greater understanding of complex topics. AR and VR

representations are intrinsically interactive, which is considered particularly effective for learning activities and fundamental for improving the general understanding and learning process. This aspect relates to the users' body engagement and refers to the well-known psychological theory of embodied cognition. Embodied cognition theory suggests that cognition is deeply grounded in sensory-motor experiences, and cognitive skills are obtained by a dynamic interplay between neural and non-neural processes. Considering this theory, the body intrinsically constrains, regulates, and shapes the nature of mental activity [7]. This aspect leads to the consideration that when the body is involved in the experience, better learning performances are achieved as compared to when the experience is more passive, consisting of mere observation or listening without presenting interactive elements. For these reasons, the adoption of VR technologies for educational purposes has expanded considerably in the last 30 years [22].

Many research studies report that VR is adopted in university-level education in different fields of application. An intelligent learning environment has been developed and applied on numerous subjects of a Computer Science degree at the University of Madrid [8].

VR immersive experience is reported as a means for aiding the design of architectural spatial experiences at Ball State University [2]. Another example is represented by the Virtual Earthquake Engineering Lab to support the understanding and application of fundamental concepts related to the field of earthquake engineering [10]. There are also several examples of VR applications for teaching STEM (Science, Technology, Engineering and Mathematics) fields [5, 16, 24]. More specifically, in the case of an application for science education [16] allows students to learn and experiment without the limits of a real environment in total freedom, thanks to VR.

Despite the papers discussed so far seem to provide positive feedbacks on the application of VR/AR technologies in education, a portion of the scientific community has found no significant differences in learning outcomes between VR, AR and hands-on experiences. For example, Klahr et al. [8] experimented with the use of immersive virtual technologies in a laboratory class, showing that physical and virtual environments do not produce significant differences in terms of learning outcomes. Similar conclusions have been drawn by Lamb et al. [9].

Despite the advantages offered by VR educational tools, it has also been demonstrated that immersive VR can possibly cause more presence, decreasing learning performances [14]. This is probably because realistic details of VR environments can improve the immersion and learner's sense of presence but can also interfere with the reflection and learning process, distracting the focus from the topic [16]. These conflicting conclusions are the results of different experimental settings, the specific field of application, the experience of the involved users with digital technologies and, obviously, the implementation details (e.g., realism of the render, smoothness of the experience, interaction modalities, etc.).

Consequently, in VR environments for learning purposes it is important to balance the level of immersiveness, stimuli and learning goals. Despite higher level of interaction with the VR environments leading to more effective concept learning, the use of interactivity for every possible action should be avoided, while a combination of user control and automation will often be appropriate [26].

3 MAIN IDEA

To make the learning of subjects such as technical representation and 3D modeling of objects more effective and attractive for students of the M.Sc in Design & Engineering, we have developed a VR application with which students can interact for active learning and to gain practical experience.

The VR application has been designed paying particular attention to the design of the User eXperience (UX) **Error! Reference source not found.**, to create a positive and engaging experience for students, which can help to improve learning outcomes and retention. Therefore,

we have considered the needs and preferences of the target students, as well as the goals and objectives of the learning program.

The VR application can be experienced using an HMD that allows the recreation of an immersive environment and allows students to view the product in real scale, manipulate the components and better explore them from different perspectives. In particular, the VR application aims to teach students: 1) the technical names of mechanical parts 2) the explosion of the 3D CAD model of a mechanical part 3) how to assemble the components of an object in the right order, and 4) how to create the 3D model of an object that is represented in a 2D technical drawing, i.e., the model of a scooter.
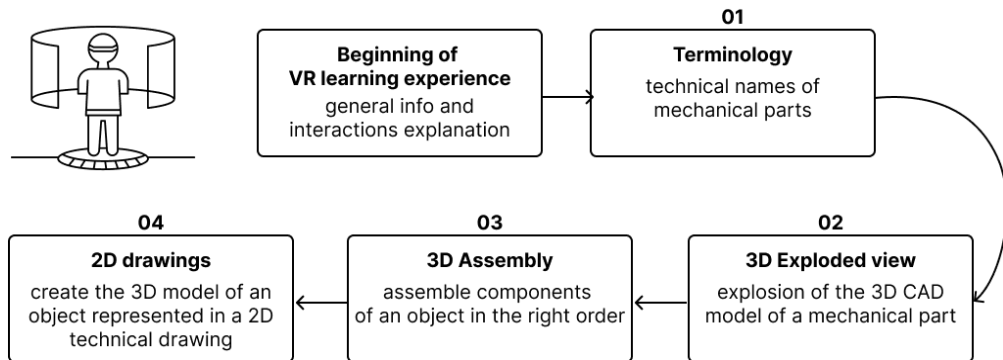

Figure 1: Students' learning journey.

3.1   VR Learning Application

The VR application offers four interactive exercises, each presented in a learning room dedicated to one of the objectives mentioned above (Fig. 1), namely: Terminology, 3D Exploded view, 3D Assembly, and 2D Drawings. The experience is guided to present the exercises following an established sequence. When students finish an exercise, an interaction panel showing positive feedback appears, and they can click on a button to go directly to the next room. The Graphical User Interface (GUI) of the application is intuitive and easy to navigate and incorporates interactive elements and multimedia content to keep students engaged. The students can see the VR environment through the Meta Quest 2 headset and can interact with VR objects through the headset's controllers. Specifically, students can grab objects, display animations, and interact with GUI elements using both controllers. Text instructions are used to provide information about the contents and guide students in using the VR application.

For the purpose of the study, the four exercises have been realized proposing a 3D scooter, considered both as the whole object and also focusing on some specific components forming just the scooter wheel.

At the beginning of the experience, a panel provides a general explanation of the VR learning application objectives, tasks and methods of interaction. In this way, students can understand that they will perform four exercises, displayed automatically one after the other, in which they will be presented with some information and asked to interact with different elements. Then, by clicking on the "Start" GUI button, students are automatically teleported inside the first room, in which the first exercise can begin.

The first room is named Terminology and allows students to see a scooter 3D model on a real scale with the aim of learning the names of the many components it is formed by selecting them separately. The selection is implemented by means of the pointing interaction metaphor [10], adopted by using the controllers. The 3D model of the scooter is presented assembled and small 3D spheres are placed close to each part of the scooter to indicate them and facilitate the interaction. When the student selects a sphere, the corresponding part on the scooter is lighted up

by using a white color and a GUI panel with the name of the part appears close to it. During the experience, a GUI panel shows some information about the relationship between the parts, presenting a specific terminology and the whole product. In addition, a voice-over is used to present the same information also in the form of audio to support the content's comprehension and learning.

In the second room, called 3D Exploded Views, one of the scooter's mechanical components, the bearing, is displayed in an exploded view so that students can learn what its components are. The component is presented on a desk in front of the student, and by selecting a physical button located on the desk, the system displays an animation of the component's 3D exploded view. During the experience, a GUI panel reports the definition of an exploded view, referring to the single parts and assembly as well. The text is supported by audio voice, as in the previous exercise.

The third room is called 3D Assembly and allows students to gain experience in assembling the components of the bearing, according to the assembly sequence learnt in the previous room. At the beginning of this exercise, a 3D component is presented at the center of the table, and the student needs to assemble the other parts on it, to create the final object. When the student selects a part, the corresponding volume appears transparently on the main component, indicating where the selected part must be placed to complete the assembly. When the two shapes match, it means that the task has been completed correctly and the student can start a new interaction. The students can repeat the exercise several times as long as the result is not correct. During the exercise, a panel, supported by the audio track, presents some information about the assembly and sub-assembly of a product, also making connections to CAD software approaches.

In the last room, named 2D Drawing, the students learn the modeling process for creating the 3D model of the object represented in the 2D technical drawing. The 2D drawing is displayed as a vertical panel on the wall, while the 3D model appears on a desk in front of the student. By selecting a physical button located on the desk, the student can start an animation that shows the sequence of features of CAD software and the tools used for creating a 3D model part. The animation shows each feature starting from the corresponding 2D drawing and displays its name (e.g., sketch, extruded cut, extruded base, etc.) through a GUI panel. In addition, a definition of CAD features and features examples are provided to the student both in the form of GUI text and audio.

Figure 2: Learning rooms of the VR application: (a) Terminology, (b) 3D Exploded view, (c) 3D Assembly, and (d) 2D drawings.

3.2 Implementation

The VR application has been developed using Unity (unity.com), a well-known development platform for games, which is nowadays used to develop VR applications for many other sectors, including design, engineering, manufacturing, and many others. Four different scenes have been designed inside Unity, corresponding to the four learning rooms. Each room is based on a common VR environment that presents an interior garage, with tables, drawers, machine parts, boxes, and shelves. The 3D model of the environment has been freely downloaded from the Unity Asset Store[1]. Moreover, this Asset has been selected for its simplicity, to be more focused on the implementation of components and actions, rather than on the virtual context, the environment being not the focus of the experience.

The interactive 3D models included in the virtual rooms have been developed by using the CAD tool SolidWorks, exported as polygonal mesh (i.e., .fbx) and imported inside Unity, paying attention on preserving the assembly hierarchy. Moreover, a set of 3D models has also been exported from the CAD software to support the animation showing the modeling sequence presented in the 2D Drawing room: from the CAD software, a polygonal mesh has been saved for every step of the modeling sequence and imported to Unity. The materials, animations, and interactions presented in the VR application have been directly developed inside Unity. Different scripts have been used to implement the interactions, mainly exploiting the colliders, a component that define the shape of an object for the purposes of physical collisions.

Graphical User Interface (GUI) elements have been used to guide the students in performing the correct actions and in presenting the information throughout the exercises. The GUI design is simple, not to be too intrusive, presenting mainly black panel backgrounds and white texts. In each room, some panels indicate the action to perform and the instructions for doing it correctly. In addition, further GUI panels appear directly above the displayed 3D components, reporting some textual information accordingly. The texts have been created using the TextMeshPro (TMP) Unity package, which uses advanced text rendering techniques to deliver high visual quality.

4 TESTING SESSIONS

A first preliminary was conducted with a group of students from the course of Virtual and Physical Prototyping at the School of Design, Politecnico di Milano. The test aimed to evaluate the User eXperience (UX) of the students, i.e., the overall experience of the students while interacting with the education VR application. The evaluation included the students' perception of the ease of use, usefulness, and enjoyment of the learning experience. The results of the preliminary test were positive, and the students evaluated the virtual learning experience as engaging and motivating. After evaluating the overall User eXperience of the application, other structured tests were conducted, with the aim of accessing mainly the learning and comprehension of the presented content and the sense of presence experienced during the use of the VR learning application.

4.1 Participants and Questionnaires

The experiment was conducted on 10 participants (6 female and 4 male) who voluntarily participated in the testing session and consented to acquire data for the purpose of the experiment. The participants involved were students from Engineering and Design courses of Politecnico di Milano, both Italian and foreign (5 from Italy and 5 from China).

Before the experience, a preliminary questionnaire to access the starting knowledge in relation to 2D technical drawings and MCAD software was conducted. This questionnaire presented both open and closed questions, asking the students to self-evaluate their knowledge level by using a 7-point Likert scale and to indicate which MCAD software they already know and use. After compiling this questionnaire, the participants were asked to have the virtual learning experience

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[1] *https://assetstore.unity.com/packages/3d/props/interior/simple-garage-197251*

by using a MetaQuest2 headset and to complete the four proposed virtual exercises. The duration of the VR learning experience was between 12 and 17 minutes to prevent students from feeling dizzy and to avoid the battery of the devices running down.

During the experience, two experimenters were at their disposal to help participants in case of need. After the experience, the participants were asked to compile two more questionnaires, one related to the contents learned during the virtual class and one related to the sense of presence experienced in the virtual environment. The questionnaire related to the learning performances presented 6 multiple-choice questions designed based on the contents presented during the virtual experience through the texts, audio-tacks, and interactions. The questions investigated aspects such as the parts of a 3D model, the 3D assembly and 3D exploded views, the relation between a 2D technical drawing and a 3D model, and the MCAD software features.

The sense of presence questionnaire was structured in reference to the Witmer and Singer [27] one, which explored different aspects that influence involvement and immersion. Specifically, the 27 questions are classified, taking into consideration four main factors: Control Factors (CF), Sensory Factors (SF), Distraction Factors (DF), and Realism Factors (RF). In addition, it has been decided to also take into consideration the subscale categories related to the Involvement/Control (INV/C), Natural (NAT), Auditory (AUD), Haptic (HAPTC), Resolution (RES), Interface Quality (IFQUAL) factors, inside the virtual environment. Most of the questions (25 out of 27) present the aforementioned factors, while the subscales are associated just with 23 questions.

4.2   Analysis of the Collected Data

The results of the preliminary questionnaire showed that 4 out of 10 participants have never attended courses on 2D technical drawing, and 3 out of 10 people evaluated themselves as not or little acknowledged about 2D technical drawings, indicating values such as 1 and 2 on the proposed Likert scale. In addition, 3 out of 10 participants reported that they had never heard of MCAD software, while 2 claimed to have used software in the past, and only 1 person continued using MCAD software on a daily basis. In these cases, the software indicated by the students was Solidworks. In addition, 5 students out of 10 self-judged their knowledge of MCAD software with values of 1 and 2 on the Likert scale. This preliminary questionnaire allowed us to point out that only 3 people out of 10 judged themselves as already acknowledged on the topic of the virtual learning application before performing the experience, presenting average values equal or higher than 4 on the 7-point Likert scale.

Concerning the questionnaire adopted to assess the learning performances, the results reported that participants gave the 78.3% of correct answers. Considering the 6 questions, the last one related to the examples of MCAD features reported the lowest rate of 60% of correct answers.

Moreover, based on the background questionnaire proposed before the virtual experience, the results of participants were divided into two groups to understand better the impact of the virtual experience in relation to people with no previous knowledge of 2D drawings or MCAD software aspects. Indeed, as mentioned before, some people presented previous knowledge on the proposed topics. In particular, 3 participants self-evaluated their knowledge with a high level by using the 7-point Likert scale and declared that they had used MCAD software in the past or at the moment of the experiment on a daily basis.

Comparing the results of the learning performances obtained from the two groups, it emerged that the correct answer rate is quite equivalent for both groups, presenting 77,7% for the expert group and 78,5% for the not expert group of correct answers. In spite of the average obtained, the not expert group generally presented a higher number of correct answers, as shown in Figure 3. These results showed that the information was successfully delivered and acquired by participants who presented no previous knowledge about the topics proposed.
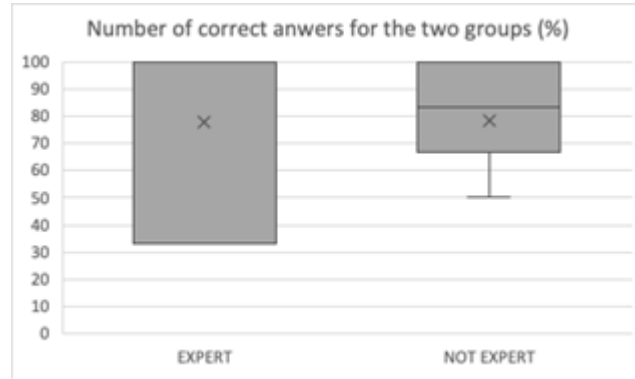
Figure 3: Graph showing the percentage of correct answers and the average value, in relation to the expert and not expert group.

Regarding the questionnaire evaluating the sense of presence, the values of the questions presenting a negative declination have been converted into positive ones. In this way, it has been possible to group the questions belonging to the same category and to compare the results of the various categories.

Generally speaking, the virtual learning experience has been positively evaluated by the students, presenting high average results (higher than 4 out of 7) for both the factors and subscales, as shown in Figure 4. Specifically, the analysis showed that the factors that had more impact on the sense of presence were the SF and the DF, with averages of around 5 out of 7. On the contrary, considering the subscales, the NATRL and the HAPTC presented less relevant results, with an average of 4.4 and 4.5, respectively. Among the subscales, the AUD subscale has been positively evaluated by presenting an average of 5.5.
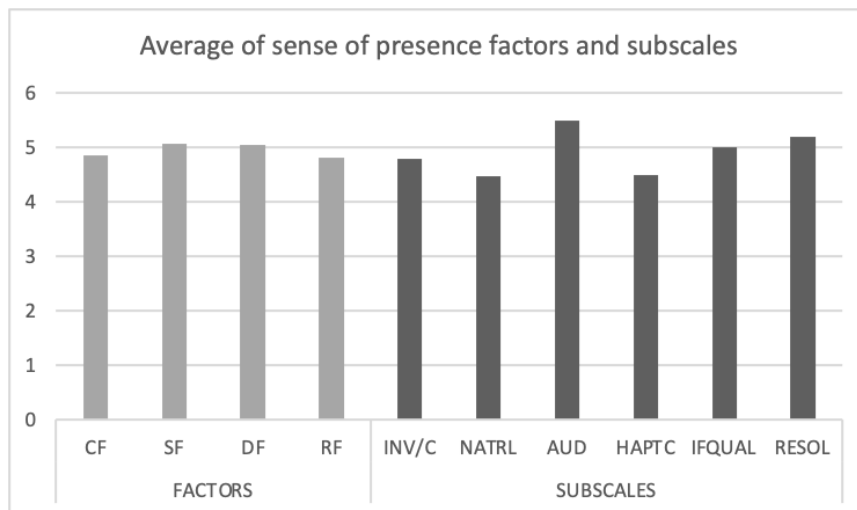

Figure 4: Results showing the average for the factors and subscales in relation to the sense of presence.

5   CONCLUSIONS

The research presented in this paper was motivated by the assumption that active learning is more effective than passive learning as it helps students better understand and retain information. Hands-on experience demonstrated to be an excellent learning method based on direct participation of students into the learning contents.

VR technology was used to implement active learning environments and hands-on experiences for the students of the course of "Methods and tools for detailed design", at the School of Design, Politecnico di Milano. VR can be effectively used to incentivize students to learn and experiment, as this approach is more engaging than traditional learning methods.

Some preliminary tests of the VR learning application demonstrated that the approach is appreciated by the students. The approach showed positive results in terms of knowledge acquisition, as students can review concepts as many times as needed, and the interactive and immersive virtual environment is more fun and engaging. Despite cost and bulkiness and low quality of equipment, demand for Virtual Reality in education is expected to grow in the coming years.

Subsequent activity plans the realization of more systematic tests to measure the performance of the proposed method by enlarging the number of students involved to get statistically robust results. Moreover, in the future, there is the determination to compare the VR learning application with a more standard e-learning system, to evaluate the effectiveness of the chosen method, and with more participants, to collect statistically relevant data. From the application perspective, two main improvements will be implemented. We believe that the introduction of collaborative features (e.g., the teacher can actively participate to the experience while the students are immersed within it) can really improve the effectiveness of the VR-based learning approach, especially when this is carried out asynchronously and/or remotely. The second feature regards the possibility for the students to access a library of models, prepared by the teachers: this will be done by creating a meta-structure of 3D models with associated naming and relations, that can be automatically loaded into the VR learning applications.

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