Title:
Virtual Reality in education to enable active learning and hands-on experience

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Introduction:
"Methods and tools for detailed design" is one of the subjects taught to students of the 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 some 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 [12]. 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 more the students. 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. Virtual Reality 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, Virtual Reality can play a unique role in addressing the educational challenges and offer the possibility for learners to better learn and retain contents [6]. Besides, VR technology allows creating immersive experiences which are attractive for young students, who use 3D and Virtual Reality technologies in their personal life.

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.

Related works

Literature suggests that Virtual Reality and Augmented Reality in education can improve student outcomes. For example, in a March 2019 report, EdTech cites a study showing that students in a Mixed Reality biology classroom received higher scores than other students [5]. 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 [5].

Numerous studies are now investigating the impact of using immersive visualization to teach scientific and technical concepts. Starting from the fundamentals of scientific disciplines, VR has been proven effective where visualization is a key element to help students mastering a concept, such as in 3D vector and vector algebra [2]. More advanced concepts have been also given an attempt: in [13], traditional hands-on have been "augmented" with a Mixed Reality (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, auditory) are provided. In [7], 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. When using AR, the cognitive and physiological response to the mediated environment seem to be weaker, allowing the user to pay more attention to other sources of information (e.g., auditory). Moro et al. [11] compared VR, AR or tablet-based simulations when teaching medical science and, despite they all enhance learning, no significant difference is observed among them.

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 the use of immersive technologies (VR) 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].

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.).

Main idea

In order to make the learning of subjects as technical representation and 3D modeling of objects more effective and more attractive for students of the M.Sc in Design & Engineering, we have developed a VR application with which the student 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) [1], 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 allows the 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.

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: Annotation, Exploded view, Assembly, and 2D drawings. 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 Oculus Quest 2 headset and can interact with VR objects through the headset's controllers. Specifically, the student can move from one room to the other by teleportation, using the right controller of the Oculus Quest 2. Text instructions are used to guide the students using the VR application, as mentioned above.

At the beginning of the experience, a panel provides a general explanation of the methods of interaction. Then the student is free to move around the virtual space and enter the specific room where perform the exercise.

The first room is named *Annotation* and allows the students to see the scooter in real scale, to learn the names of the many components by selecting them. The selection is implemented by means of the pointing interaction metaphor [10]. The 3D model of the scooter is presented assembled and small 3D spheres were placed close to each part of the scooter to facilitate the interaction. When the student selects a sphere, this will reveal a GUI panel with the name of the part, which appears close to it.

In the second room, called *Exploded Views*, it is displayed the exploded view of one of the scooter mechanical components, the bearing, so that the students can learn what are the components. Selecting le animation button, the system displays an animation of the exploded view.

The third room is called *Assembly* and allows students to gain experience of 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 final result is not correct.

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 students can start an animation that displays the sequence of features of the SolidWorks CAD tools used for creating the 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.

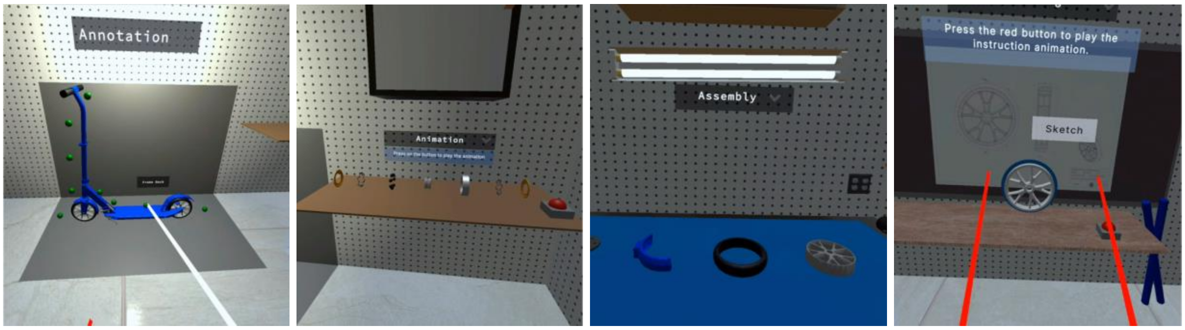

Fig. 1: Learning rooms of the VR application: (a) Annotation, (b) Exploded view, (c) Assembly, and (d) 2D drawings.

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 [3], mainly to save time during the development of the application. Moreover, this Asset has been selected for its simplicity, in order to be more focused on the implementation of components and actions, rather than on the virtual context, being the environment not the focus of the experience.

The interactive 3D models included in the virtual rooms have been developed by using the CAD tool SolidWorks and imported inside Unity, divided into sub-parts. 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 Unity colliders.

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) [4] Unity package, which uses advanced text rendering techniques to deliver high visual quality.

Test

The application was preliminarily tested by a group of students from the course of Virtual and Physical Prototyping of the School of Design, Politecnico di Milano, who are colleagues of the students who developed the VR application. The aim of the test was 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 includes the students' perception of the ease of use, usefulness, and enjoyment of the learning experience.

The duration of the VR learning experience was between 12 and 17 minutes, to prevent students from feeling dizzy and that the battery of the devices run down. The results of the preliminary test were positive, and the students evaluated the virtual learning experience as engaging and motivating.

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 has demonstrated to be an excellent learning method based on direct participation of students into the learning contents.

Virtual Reality technology has been 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 Schools of Design, Politecnico di Milano. VR can be effectively used to incentivize students to learn and experiment, as this approach is more engaging and fun than traditional learning methods.

Some preliminary tests of the VR learning application have demonstrated that the approach is appreciated by the students. The approach has demonstrated 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 in a more scientific and quantitative way. Besides, it will be implemented a meta structure of 3D models with associated naming and relations, that can be automatically loaded into the VR learning applications, so that students can learn and make experience with many different objects.

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