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Augmented Reality experiment in higher education, for complex system appropriation in mechanical design

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Abstract

Virtual representations are quite widely used in higher education to visualize a design model or simulation. Nevertheless, many students have difficulty grasping mechanical systems, from a 2D design plan or a 3D CAD definition.
This is why we implement real system manipulations, associated with various representations, especially for students with no technological skills. Augmented reality can provide an answer to the difficulty of making the link between a representation and the real system.
Since augmented reality has not yet been used in mechanical design pedagogy, the challenge was to evaluate the relevance of this technology to facilitate understanding of mechanisms. An augmented reality scenario has been implemented on an electromechanical mechanism. It makes it possible to identify components and their locations, to explore the mechanism and thus more easily identify the kinematic chain or transmission power flow for example. Two different interfaces were used by the learners (tablet and HoloLens glasses), each of which has its advantages.
The first experiment was conducted with students in engineering training, as well as bachelor of technology students. During analysis of mechanism practical session, half of the workforce used augmented reality, while the others had only paper documentation and cad. At the end of the session, an assessment of the system's understanding was conducted 'hot' and shows improvements for augmented reality users.
Here, augmented reality is used in pedagogy, as a new medium support to pedagogy. But this experience is also relevant for introducing engineering students to a relevant technology for industry of the future, enabling them to measure the potential of augmented reality.

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1. Definitions

Milgram and Kishimo have defined augmented reality (AR), as a technique which enriches reality by superimposing a layer of information or numerical contents [1]. The mixed reality comprises augmented reality and augmented virtuality (figure 1). AR has more real elements than virtual ones, whereas in augmented virtuality, real elements are added to a virtual world.

For mixed reality the visual aspect of the experience is essential, but it is possible to integrate other sensorial models such as touch (haptic feedback) or sound (which can be put in space). This is particularly the case when the user can interact with numerical and real objects while maintaining a presence in the physical world [2].

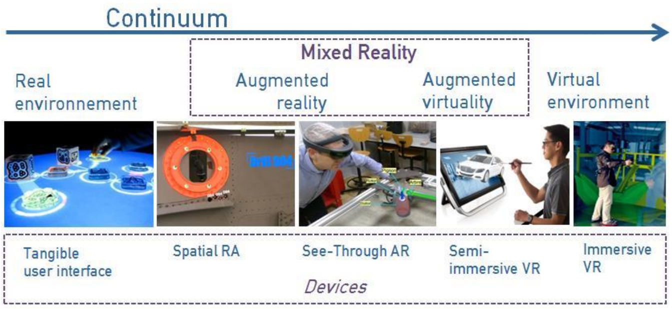

Fig 1. Continuum of environments from real to virtual and associated devices

Thus, these techniques aim at improving the interaction of the users with the physical environment, rather than separating

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them from it. This implies three rules the AR system has to respect according to Azuma : combine the real and the virtual, be interactive in real time, and be conceived in 3D [3]. The difficulty lies in aligning the real and virtual worlds on the same perspective when the user is changing his position, in a robust and reproducible way [4].

The stationary and mobile AR systems are thus built based on a common material architecture :

- a camera filming the scene viewed by the user (case of the tablet) or a semi-transparent helmet worn by the user (Optical See Through) case of the Hololens glasses,
- a computer to generate the virtual entities,
- a numerical display,
- sensors giving the position of the user and of objects in the real environment.

The interaction with the user is made either using a tangible interface (tactile surface of the tablet), either by a gestural interface for the Hololens glasses.

2. Context and actual uses of augmented reality

The Gartner cabinet measures with the Hype Cycle [2], the risk/opportunity ratio for each technology in time. Five phases characterize their adoption. The progression of augmented reality is shown : after having known a phase of decline, it's now a phase of renewal and draws near to technical maturity.

Among the companies which were the object of the Capgemini study in the spring of 2018 [5], 600 have already experimented or implemented AR and VR techniques. They see more contribution and relevance in AR than in VR but the complexity and the implementation seem more important. For example, in a service company, where VR can train the users, AR is a source of added value in risky situations, notifying the user in a maintenance situation of risks invisible to the naked eye (if a part is very hot or if a wire is plugged).

The present implementation sectors are numerous : medicine, marketing, military, tourism, architecture and contracting, cultural aspects [6]. But according to Havard [7], half of the AR uses in an industrial context are made in the maintenance sector, and to a lesser degree one fourth to help maintenance as well as for training or for logistic purposes. Palmarini et al. have studied different AR applications in maintenance [8]. They concern mainly mechanical or plant maintenance as well as the aviation industry. These maintenance operations concern mainly assembling/ disassembling (33%), repairing (26%), inspection/ diagnosis (26%) and training (15%).

By 2022, 70% of the companies will experiment immersive technologies meant for consumers and for companies, and 25% will have put them in production [2].

3. Relevance and advantages of augmented reality in an engineering context

When working on a real system, the use of written information and instructions can be difficult and lead to mistakes. Whether in an industrial context or in training, AR brings solutions to these difficulties. The understanding of written instructions, the teaching of subjects needing spatial components and even the training in technical gestures (notably in science, engineering and medicine) are made easier [9].

3.1. In the industry

According to Cohen and al. [5], industries tend to go to a pragmatic use of augmented reality, and they notice that these techniques improve the productivity of the operators.

Globally, the present experiences using AR put forward an increase in efficiency, in security as well as a time gain in operations. For example, Boeing uses it to provide instruction regarding plane wiring, and that generates a reduction in production time of 25%, and a reduction in the rate of errors [10]. When the use is linked to a manufacturing task, AR brings the configuration and assembly instructions. Renault Trucks is testing AR for the quality control of its engines, so as to display the instructions guiding the operator step by step. Renault has also shown the potential AR has for assembling [11].

In the industrial field, AR is very relevant for assembling but also for maintenance [3][7] : Technicians usually refer to a manual. This creates a high cognitive load due to the permanent shifting of the attention from the manual to the device during maintenance; this is a source of errors and takes too much time. With AR, the information and the gestures are superimposed on the system the operator is working on [12]. Augmented reality gives a free hand access to step by step immersive instructions, while the operator is working manually. For Safran, AR is a maintenance aid solution because the documentation that defines official repair procedures is not directly uasble by operators and requires interpretation and experience. Their AR application immediately provides technicians with working instructions with the configuration of the product on which the maintenance operation is carried out.

Finally AR brings an answer to the collaboration need between expert and operator [7] : For now the expert shares his knowledge through assembling or maintenance documents. The operations can now be guided with an augmented reality guide prepared beforehand; or be synchronously guided by a distant co-worker. For example, communication with a distant expert who sees live what difficulties the operator is facing, and the transmission of step by step guidance and instructions, reduces up to 40% of intervention time at Porsche [13].

So, when the main uses are for repairing and maintenance, the relevant functionalities are then :

- have access to numerical manuals,
- visualize the components and functions beyond the physical barriers,
- superimpose the instructions step by step,
- allow the transmission of situations to a distant expert , and the sending to the operator of targeted information.

3.2. In an education context

According to Anastassova and al., training is one of the favorite domains of AR, because this technique allows a double support real-virtual to the activity of the learner by giving him contextualized information [14].

The interest of AR in an education context is highlighted by several authors : According to Fjeld [15], learning by doing and in situation allows to build knowledge in an active and autonomous way. Cieutat and al. indicate that in the case of practical work, the systems using AR can bring a "semi-determinist" aspect where everything is not foreseen beforehand and for which technology is easy to put in place [16].

In the context of mechanical engineering, the problems of system comprehension stem from the difficulties of the passing from a plane representation to volumes. AR can bring an answer because it eases the elaboration of dynamic spatial representations [17]. Moreover, the fact of showing simultaneously physical artifacts and the abstract notions related to them insures an easier understanding of technical concepts [18].

AR also allows to see as real, object with which the user interacts : this strong feeling of "presence" improves memorization [19].

Moreover, AR changes the way users and machines interact, which can lead the students to tackle the lesson topics in a different and more pro-active way [6]. The most common use of AR in education concerns interactive lessons offering 3D visualizations, this allows teachers to reduce the gap between real and virtual.

Thus, Akçayir and al. have studied the effects of AR on the elementary lab skills of students [20] : The students were able to accomplish experiments quicker, because the visual information has made these experiments easier to undertake. AR has shown its relevance in the assistance to the teaching of technical gestures [16].

Finally, AR helps visualize phenomena invisible to the naked eye, for example invisible flows on real objects such as an air flow or a magnetic field. This way AR helps better understand physicals phenomena [16].

3.3. Relevance of AR in engineering training and in mechanical design

In the case of engineering studies (notably in mechanical design), we have first identified these difficulties for students with little or no technical culture :

- The ignorance of the components and their functions,
- The reading of 2D and 3D representations,
- The identification of an internal kinematic of a mechanical system, so as to understand movement transformation or to identify a power transmission chain.
- The difficulty to make the link between 2D or 3D and the real system.

Starting with these difficulties, we have identified the relevant functionalities of an AR device to assist in learning :

a) Help to the adoption of complex systems

- Addition of information :

. Addition of virtual text on the physical object, names of parts or part groups, with, if necessary, additional information (functions, material…)

. Identify the input/output, the commands…

. Make circuits or flows appear.

- Assistance to analysis :

. exploration of mechanism assembly and break-down (virtual section, see inside a casing, nomenclature and identification of parts on the system)

. coloring of kinematic sets,

. animation of a mechanism kinematic,

. visualization of an invisible phenomenon (mechanical stress, thermal flow…).

b) Assistance in sessions of mechanical discovery, asistance in assembling / disassembling

- Identification of the real part on which to work, visualization of the tool’s place on the real mechanism,
- Animation of the actions to be made, virtual implementation of the tool, to avoid wrong gestures,
- Check the conformity of the reassembly, or the absence of a missing part.

c) Assistance to the taking in charge of a machine

- Visualize the actions to be made on a control cabine for example.
- Indicate how to make a setting,
- Identify a component to disassemble/set…

4. Implementation of an educational experience

4.1. Making of an Augmented Reality scenario

The transcription of information contained in a practical session text or in an assembly manual, in instructions, or AR scenarios is a difficulty. Another stake is to formalize the knowledge of the operators. You need the real system, its CAD modeling as well as the knowledge of the trade.

We wanted to enrich a practical session of discovery and analysis of mechanisms on a gate opening electric actuator. The different steps of the scenario making were the following :

- Import of the CAD model in 3DviaComposer and establishment of the AR scenario content (contribution of the pedagogue) : the different views allowing a progression (figure 2) : locate the main components, the input/output, identify the internal components or allowing to locate them, visualize the kinematic subgroups, identify the transformations of movement, visualize the insert of a tool in an unlocking mechanism and the way it works.
- Tracking configuration, establishment of the AR project, and transfer on the tablet or the glasses.
- Use in training, analysis and correction of the scenario.

4.2. Choice of the AR devices

Havard states that 31% of case studies in AR are done via tablets, meaning the users have a good knowledge of the tactile interactions. This does not add any difficulty when using them [7]. According to him, the Video-See-Trough devices are not meant to be transferred towards an industrial use for lack of ergonomy, which is not the case for the Optical See Trough devices (at present 17% of the case studies).

We have decided to test our educational scenario on tablets and Hololens glasses to compare the two devices. We used the Diota software because it is compatible with cad data (3DviaComposer). Moreover, to reposition itself on the real objects (the tracking), this AR software proceeds by direct recognition of part forms. In that way, the superimposed data to reality are made more realistic whatever the viewing angle.

The tracking depends on the CAD definition of the part which must be the same as the real object. But this type of software has solved occultation and rapid movement problems [22]. In the case of the Diota software, this requires an initial calibration, which can be memorized.

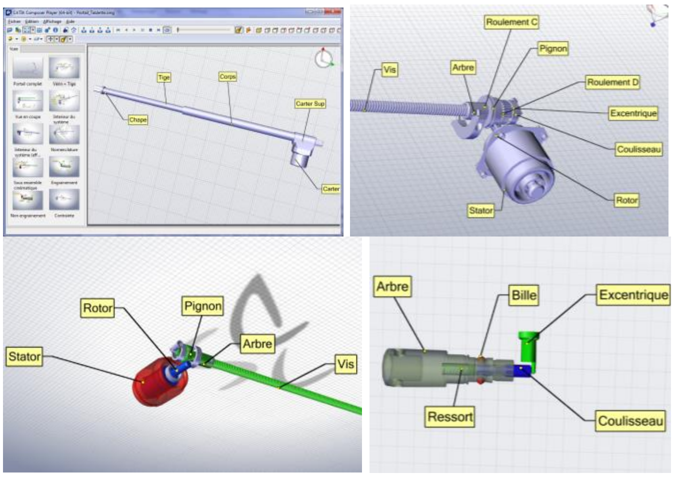

Figure 2. Overview of the scenario in the case of practical session regarding the analysis of an electric actuator (3DViaComposer®).

4.3. Condition of the experiment

Two groups of participants took part in the experiment, made at the beginning of the academic year :

- 22 students in Bachelor of Technology (2^{nd} year),
- 37 students in Arts et Métiers engineering studies (1^{st} year).

All these students didn't have specific knowledge in mechanical design or in analysis of mechanisms.

The students carried out a practical work of 3 hours in small groups (3-4) on an electric actuator. They had a blueprint, a CAD, a questionnaire guide and the real system (functional and in parts). The objective of the study is to analyze the mechanism, in order to be able to identify the functions implemented, the components of the power transmission chain, the kinematic chain ... They must also explain the operation of the locking mechanism and clutch. For each of these populations, only half of the students had access to the AR device, either on tablet and/or on HoloLens glasses. The students were free to handle the questions and understand the mechanism in their own time.

At the end, the students were asked to fill out an individual understanding sheet, specifying it was not a graded evaluation. It had questions and drawings to fill in to check if the student could locate the components, identify functions or movement transformations…

5. FIRST RESULTS

5.1. Global analysis of the experience

AR had not yet been used for this type of learning needs. We tested two devices: in the case of the tablet, reality is filmed with an on-board camera, and the viewing is displayed on the screen with other superimposed information (figure 3). The user does not see reality directly, and he does not have hands free. Besides that, the camera has to permanently 'see' the totality of the defined part as tracking reference, which makes it difficult to come very near to the mechanism.

With the Hololens glasses (figure 4), the user sees his environment directly upon which information are superimposed (holographic windows, 3D parts on the real system).

Figure 3. Tablet scenario : on the right side of Diota player, user can see informations or instructions.

Theses glasses may seem bulky and heavy. However, the tracking which does not only depend on the determined part, but also on the environment permanently scanned by the cameras of the glasses, allows to come very near to the studied system and see interesting details. Another big advantage is that the user is free of his movements. Finally, the glasses do not require a wired connection.

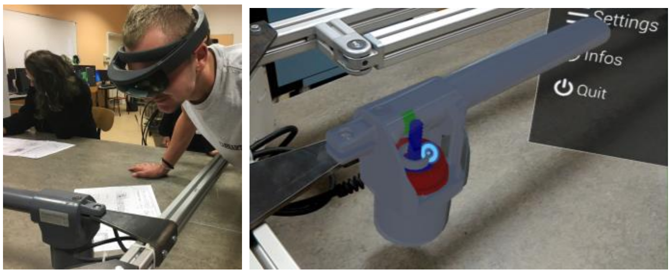

Figure 4. Hololens glasses scenario.

We have identified the first following limits :

- To achieve a display on reality without having the feeling of superimposition assumes that the reality part is well hidden. So, when making the scenario, casing parts must sometimes be kept, but they have to be rendered semi-transparent.
- The visual field is also limited with the Hololens ; they have to be correctly adjusted in front of the eyes. The head moves more than the eyes.
- With the tablet the exploration of the mechanism is less absorbing than with the superimposition of information in front of the eyes, because you go via a camera vision to a transcript on a screen.
- A visual overload can lead to a cognitive overload. It is advised to limit the number of information per viewing, and it is preferable to multiply the number of viewings.

Anastassova et al. have synthesized the works having studied the use as well as the mental and physical loads of AR systems [14]. Contrary to VR systems, the AR devices cause less sensorial problems, more specifically less "simulator's sickness" [23].

5.2. Contributions to involvement and motivation of learner

With the use of AR, the learner is in a learning by action position. This educational approach makes the learner more active so that he can build his knowledge in real life situations [16].

We noticed a strong interest in the use of AR, and numerous authors confirm that. According to Antaya, AR increases the learner's interest and arouses their commitment [9]. Anastassova also notes the increase in the learner's motivation [14]. This is due to the novelty of the interaction mode [24]. According to Di Serio and al., the students are motivated by the use of AR when it is integrated in their learning environment, and this also allows to keep their attention [25]. Akcayir and al. also notice that the students' satisfaction puts them in a positive attitude [20].

The playful aspect of AR stimulates the students commitment to their learning, but they have to go beyond this playful aspect to gain knowledge [9]. According to Sanchez and al., learning situations seen as playful encourage the learner's commitment, the decision making process, autonomy and even collaboration [26]. But we also saw that this playful aspect could harm learning: Students play with the system without grasping the necessary information for the exercise. This confirms that information per view must be limited.

Another source of commitment for the learner is autonomy. And it is in this perspective that AR also has an interest. The progressive discovery of a complex system is guided by the different views of the scenario, with a progressive content:

- A global approach to the system allows to locate the input/output, gives the names or the functions of the different visible parts.
- Additional explanations may be given in the text accompanying the viewings.
- Then animations can improve the understanding of a more complicated kinematic to grasp; it is the case for the release device of the electric actuator, the animated viewings of this mechanism helped a lot to identify its functions and how it works.

This way, the learner goes at his own pace and has the different information to help him understand the system and the way it works: name and place of parts, color of the kinematic groups, explanations (text or recordings for each viewing), animation or parts taken separately in context. He can come back to the previous viewings if necessary. AR eases the difficulty of access to the information (on a paper notice) or the difficulty to perceive and visualize a 3D kinematic chain.

The interaction is important in the learning devices, and makes the participants more active. In our case, the interactions are made through the tactile interface of the tablet or the interpreting of the gesture with the Hololens. A direct manipulation of the virtual object is not suggested, but the student can change views.

This said, the contribution is not static since an educational scenario puts forward different views, where the user discovers more and more detailed and technical information. It is thus possible to measure the progression of contribution and questions ; contrary to 2D definition on blueprints or virtual ones in CAD where the entire 3D model is presented as a block.

An interaction with the tablet interface is also possible in the case of the "nomenclature" feature: In the same way as a nomenclature gives the name and the function of a part on a map, it is here possible to locate a part on the real environment when it has been chosen on the nomenclature of the tablet. Thus the different copies of a same component are immediately identified and highlighted (figure 5).The student can also interact with the presence checking function of the part (in case of assembling).

Finally we notice that the students control the interface in an intuitive way ; they collaborate and communicate more naturally, through the physical environment.

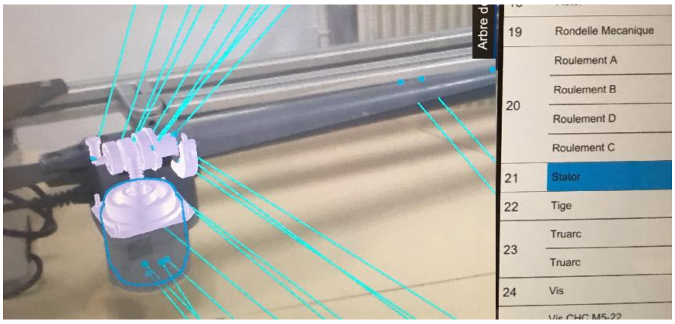

Figure 5. Identification of parts via the nomenclature (Diota player).

5.3. First evaluation of the impact of an AR experience on the understanding of the mechanism

At the end of the practical session, each student has to fill in a short individual questionnaire of understanding. It entails questions and drawings to fill in, and it allows to evaluate in a global way if the student can locate the components, identify and locate movement transformation and components involved, identify sets of parts having specific functions (a manual unlocking device for the actuator for example).

We notice that the grades of students having used AR scenarios are in majority above the average (figure 6) and that their global results are better (table 1).

So we notice that AR has allowed students to extract relevant information about the complexity of a system in a much easier way, which brings a gain in time in the understanding of the mechanism, or on the actions to be made.

Havard analyzed more use studies of AR and also noticed that this allowed to locate the task to be made more quickly, and to make less mistakes. But he also states that assessment of the contributions of AR in an industrial context still need to be ascertained [7].

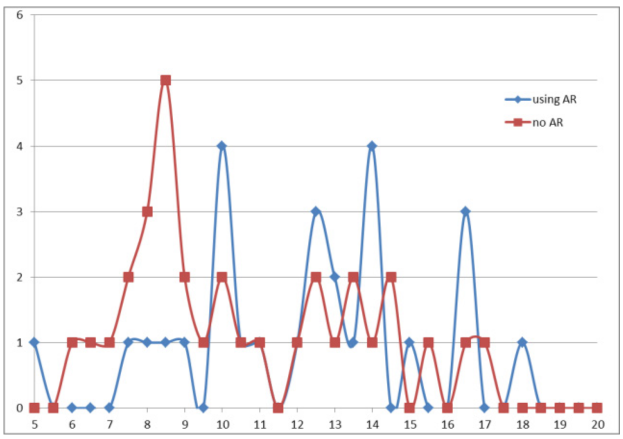

Figure 6. Grade breakdown of the comprehesion test for the 2 trainings.

In our case, after this first experience, only the results regarding the capacity of the learners to appropriate a mechanical system in a short time were evaluated. In order to improve the educational scenario, it would be a good thing to assess the usability of the AR system in an engineering educational context, meaning, does this modality allow to reach the educational goals with efficiency [27].

We haven't assessed the absence of uncomfortable situations nor the satisfaction of the users so far, but all the students were enthusiastic with the handling of the device.

Table 1. Average of the students' grades.

	AR use scenario	Without AR
Bachelor students	11,5	10,2
Engineering students	12,4	10,9

6. PERSPECTIVES

Augmented reality had not yet been evaluated in mechanical design pedagogy. We identified the relevant AR features. A first test has put forward educational contributions to the assistance of mechanical system appropriation, by helping the kinematic reading and movement transformations identification in context.

The biggest interest in AR is to bring the targeted information at the appropriate moment, and above all, at the appropriate location. This kind of AR scenario also allows the assistance in the follow-up of procedures (handling operations in practical sessions or assembling/disassembling operations).

With this first pedagogically promising experience, we are going to continue with other educational supports to test the help to the understanding of complex mechanisms. We are developing a scenario on an automobile gearbox, to help the identification of power transmission paths and the kinematic modelling. Another scenario on a turbofan plane engine will give explanations on how the engine works, will help visualize the different flows (hot or cold air, low and high pressure…) as well as the different revolving groups (turbines, compressors, reducers, low speed propellers).

The use of industrial numerical devices will require new specific skills for the new actors of industry 4.0. Here, AR is used as an educational support tool, but this experience also introduces students to a relevant technology for the industry of the future, enabling them to measure the potential of this technique and to become well-informed users or prescribers.

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