Use of haptic devices in education: A review

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***Abstract* –** Teaching STEM subjects requires making concepts as intuitive as possible, a student must relate between mathematical expressions and what he can feel and observe in real life. The golden rule for teaching is to make students participate and use as many sensations as possible (Active learning). Computers and teaching simulations have been the perfect tool for educators, but for so long they have been heavily relying on audition and sight only (passive learning). The integration of Haptic technology (Perception via touch) into these teaching simulations has helped revolutionize the educational system. the advantage of using haptic devices is that it converts passive learning into active learning, which is considered to be the core of teaching STEM subjects, as they rely on lots of practical(hands-on) work.it offers a physical interaction between students and the phenomena required to comprehend. This review introduces haptic technology and how it can be utilized in education, discuss the benefits of active learning and its advantages over passive learning, Covers the latest haptic devices used in the different educational fields, Covers the challenges facing the wide spread usage of this technology, and finally Gives hints on how this technology can be further utilized.

Keywords: Education, Haptics, Force feedback devices, Vibrotactile Device, Active learning, educational Simulations, Wearable device. STEM.

I. INTRODUCTION

In many professions, you need to excel at STEM subjects (science, technology, engineering and math). these subjects require a complete comprehension and understanding, but most of the times they are not that simple. For example, Physics is the back bone of most engineering fields such as: mechanical engineering, electrical engineering, and civil engineering.as an engineering student, you need to have a strong connection between mathematical concepts and their applications in real life (engineering is just the application of physics in real life). this connection is built and strengthened over time through practical work and conducting experiments. The more practice, the stronger that connection is. This is called active learning .it means that students need to engage and participate in the learning process. They are to read, write, search, communicate, discuss, conduct experiments, solve, share and get feedback. (Teachers or professors) are just there to guide, create problems, and give feedback. Teaching has been dependent on traditional methods which rely on the two sensations of audition and sight. Practical experiments are not always available, affordable, or cheap. most of the time teachers make do with what they have got. Computer technology and virtual reality simulations have achieved a great success over the years. They revolutionized the educational process. despite all this, there is still a lack of immersiveness. This is not ideal for an engineering student. There are a lot of physical phenomena that cannot be taught via sight and audition such as electrical fields, charge, voltage, resistance, magnetism, force vectors, thermodynamics, harmonic motion, gravity. These phenomena are invisible. they need to be felt. They require the spatial ability of the human body [1]. it's been proven that our nervous system can benefit the most from outside stimulus when touch, vision, and audition are combined together [2]. Haptic technology is the solution to this problem.it is use of devices that stimulate the feel of touch. (tactile, kinesthetic, thermal) sensors are dominant over the human body compared to ears and eyes. The integration of haptic technology into traditional learning methods adds a feel of realism [3]. Many studies have been conducted and new devices have been developed in many fields like: Robotics for children [4] [5], Robotics for undergraduate [6], Physics & engineering [7], Medicine [7] [8] [9], mechanics [10] and Chemistry [11]. Haptic devices can be extensively used in education if made affordable. the focus in the recent years was on making haptics cost effective for the widespread usage in schools, universities, and even in homes. Vibrotactile devices are far the most economic between haptic devices, yet they have proven to be very effective. The human hand is considered to be a miracle when measuring the amount of sensors, it.it can sense vibration and recognize amplitude, frequency and the duration of a vibrotactile stimuli [12]. In this review we introduce haptic technology and how it helps in education and active learning. We then discuss the recent devices used in educational field, mention some of the problems facing the use of this technology on a large scale. And suggest some solutions.

II. Haptics

Haptics is the perception of the ambient environment via touch. Touch is the most dominant sensation because touch receptors are located all over the skin which covers the entire body. There are thermos-receptors which sense temperature, nociceptors which sense pain (damage to the skin), and most importantly mechanoreceptors which sense pressure (forces, vibrations, and textures). Mechano-receptors consists of two types: tactile receptors found on the outer layer of the skin which can sense pressure (strain to the skin), and kinesthetic receptors found inside the joints which can sense position and

forces to the joints [13], [14]. These haptic sensors give us the feeling of presence in our environment.

2.1 Traditional passive learning vs active learning

for so long and up until this moment, teaching has focused on delivering information to the students in the simplest way possible in which the instructor presents the students with some information and the students memorize it. this is called passive learning where there is neither contribution from students nor feedback from teachers. About 60% of the educated population are passive learners [15]. This method is not effective especially when it comes to professions that requires deep comprehension of STEM subjects such as: engineering, medicine, astrophysics, biology, chemistry, data analysis, and so on. Active learning in contrast is student centered .it is based on practical work where the student receives information, discuss it, apply it in case studies, and get feedback from the instructor. Active learners gain higher thinking skills, and are well equipped to face new challenges in their fields. STEM students perform better with active learning [16]. multi modal learning has proven to be more effective. practical work is always preferred.it uses as many senses without even knowing. Vision is used for shape recognition, pattern recognition, and motion tracing. it's very fast and focuses on the whole picture. haptics on the other hand is used to recognize the details such as weight, texture, friction, temperature [17]. The domination of one over the other depends on the situation.one might replace the other [18], but working together is always preferred.

2.2 Computers and simulations

After the rise of Microsoft and apple in 1975 and 1976, the UK started the council of educational technology(CET). Since then, education has been shifting from traditional methods which was only (audio-visual) into computer based learning. the (CET) defined educational technology as "Developing and applying of systems that improve human learning process" [19]. computer simulations were developed for teaching purposes. They were used to visualize mathematical modeling of real – life phenomena and interact with them as you would do with real life scenarios. they outperformed traditional methods which focused most of the times on the imagination of students. Recently VR glasses were developed for better experience. but they were just improvement of the existing audio-visual methods. Haptics was first introduced in 1931.it was used to overcome the lack of sense of realism as it helped students feel forces inside virtual simulations [20], [21] nowadays it's heavily integrated into simulators for greater sense of immersiveness. touch is the only sense that works in a closed loop. The user can both exert force and sense the feedback at the same time. This is why it's the prefect tool for learning especially the human hand because it's the most condensed part in the human body in the amount of touch receptors. "What the hand does, the mind remembers." – Dr. Maria Montessori. Nowadays, the research is done on how to use haptics more in the educational field.

2.3 Types of Haptic devices

Haptic devices can be classified into 5 types: Force-feedback, electrotactile, vibrotactile, ultrasonic, and thermal. force-feedback devices(kinesthetic) exert forces on muscles and ligaments attached to joints, these muscles are linked to the brain in a way that it can feel the position and motion of the outer limbs. They can work with large area of the human body. The only drawback is that most of the times the device may be large, not portable, and can hinder the freedom of motion of the human body. They can be very complex and hence very expensive. Electrotactile devices deliver electrical signals with specific amplitude and frequency to muscles and nerve endings to make the user feel sensations of tension or compression as if they were real life forces. Vibrotactile devices are far the most used and spread among haptic devices. They can deliver vibrations to the outer layer of the skin on any part of the human body. the mechano-receptors can translate these vibrations in the form of forces. They might not deliver as much force as force feedback devices, but they can be very small, compact, and cheap. Ultrasonic devices can use sound waves and concentrate them on a part of the body so that it can feel force as if something was there. They can be complex and expensive. Finally, thermal haptic devices can control the temperature of the human body partially or completely. The body cannot accurately locate the center of heat or cold so the device can be very simple and compatible. It's not widely used as it does not deliver forces. Now We mention some of the devices used in different educational fields.

2.4 Applications of haptic devices in different fields

In medicine, Students deal with specific kinds of motion like medicine where they train to make incisions in a specific manner. A good doctor must have a good muscle memory (moving his hands without the need to look).in the past doctors used to train on cadavers.it was cost ineffective but nowadays with the help of recent technology doctors almost train all the time using simulators with force feedback. VCSim (Virtual Catheterization Simulator) is a simulator which combines VR technology and haptic technology to train cardiovascular interventionists [22]. another simulator is used for training doctors to place kirschner wires for fractures [23]. the da Vinci Xi is used for training doctors and for real life minimally invasive surgeries [24] [25]. a device that could generate Airborne Ultrasound is used for training medical students on palpation which is a core skill for any doctor [26].

for engineering students, the haptic paddle is a device used to mimic the output force of mechanical components such as mass, spring, and damper.it can mimic every component alone, and can do combinations of them [27]. wearable devices(exoskeletons) can be used to feel forces of mechanical systems like in the TESLAGLOVE which is used in teaching simulators. Some Haptic devices can even be assembled as a training itself, and used to teach dynamics and controls when used in simulation [28] [29]. video games joystick can be

reprogmmed to work with developed simulations to teach engineering students about moment of inertia, internal forces diagrams, and statics reaction problems [30]. another study used the same joystick to mimic the force generated from levers, pullies, screws, and wheel and axles [31]. The tesla suit is a full body suit that delivers tactile forces anywhere on the human body [32].it can be used in engineering simulations where a student uses VR glasses to conduct experiments in physics, math, and chemistry. Vibrotactile actuators can generate forces mimicking real life forces like electrical forces and fields, magnetic forces, lift and drag forces, friction forces, and viscous forces. Many phone/computer teaching simulators uses vibration as a feedback. In some cases, Tactile information can replace audio-visual information in a very efficient manner [33].

For chemistry students, simulations are used to represent forces of chemical bonds between molecules to make the student comprehend the formation and structure of different molecules, crystals, and materials [34] [35]. This is done by scaling up the molecular structure. Thermal haptic devices can be used to represent the amount of heat generated or consumed for different chemical reactions. The Phantom haptic arm is used to move through the atomic space to feel the effect of electron density as a force.

2.5. challenges facing the wide spread use of haptics

There are two major problems challenging haptic technology; cost and portability. Force feedback devices with many degrees of freedom can be complex and hence so expensive. The huge size in most devices cannot be reduced so they are not portable in most cases. Tactile devices on the other hands are small, compatible for all devices, and portable. They can be very simple to construct and program so their price is relatively low. Haptic technology is still a newborn .it hasn't been adopted by the educational field yet. As always The driving force for the development of any new technology is the entertainment business. That's why audio-visual technologies are far more advanced because they power both filming and gaming industries. Fortunately, those two industries have been focusing on haptic technology in the recent years. That's why we video games using haptic feedback as in vibrating joysticks, vibrating steering wheels, and in exo-suits linked to VR glasses. We also find vibrating seats, and special speakers that deliver huge impulses to the audience in advanced cinemas like IMAX.so hopefully this technology will be far more studied and adopted by the education society.

2.6. Further utilization plans for the future

The long term solution of haptics scarcity is mass production. For that to happen educational institutes need to invest more in industry and make new cooperation protocols. But this takes time. Wearable tactile haptic devices are simple, portable, and cost friendly. Just one haptic device can be used in a lot of applications and fields if it is compatible.so at first we should focus haptic devices of general use. They can be used in medicine, engineering, physics, math, and chemistry. Developing applications and software compatible with haptic technology is a must for it to spread. It's no use for haptic devices if there is no apps or APIs that integrate with them. It's a fact that haptic technology is multidisplinary as it requires the work and coordination between many fields as computer software development, robotics, psychology, educational theory, Art, and all fields affected by this technology.

III. CONCLUSION

Teaching STEM subjects requires making concepts as intuitive as possible. The golden rule for teaching is to make students participate and use as many sensations as possible (Active learning). integrating Computers, teaching simulations, and Haptics has helped revolutionize the educational system. the advantage of using haptic devices is that it converts passive learning into active learning.it offers a physical interaction between students and the phenomena required to comprehend. The use of haptics in the educational field may face some economic challenges, but mass production on the long term may solve this problem. For now, more simple portable general use devices should be produced more, and all beneficiaries should contribute to the development of this technology/industry.

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