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ORIGINAL

What will the education of the future look like? How have Metaverse and Extended Reality affected the higher education systems?

¿Cómo será la educación del futuro? ¿Cómo han afectado el metaverso y la realidad extendida a los sistemas de enseñanza superior?

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ABSTRACT

Education is one of the essential foundations of the sustainable development of societies, in particular, the objectives SDG4 of the UN General Assembly. Extended Reality (XR, so-called Metaverse) enables multisensory interaction with virtual environments, computer-created objects, and avatars. Also, the dynamic development of Head Mounted Displays (HDMs) allows for an increasingly deeper experience of the virtual world, especially through the development of depth perception, including the rendering of several modalities like vision, touch, and hearing. This creates a unique opportunity to revolutionize the higher education system by adding a new dimension of cognition and making it accessible to more people, especially those living in hard-to-reach areas. It is also a perfect complement to the process of educating students during a pandemic, such as the recent COVID-19 pandemic. In this paper, based on the literature and our experience, we provided an overview of the possibility of the Metaverse application in higher education taking into account the advantages and limitations of the systems. It turned out that XR-based solutions can be successfully applied in medical education, chemistry courses as well as in Science, Technology, Engineering, and Mathematics (STEM) education. Moreover, the XR-based systems are useful for learning spatial skills such as navigation, spatial reasoning, and perception. In the case of remote learning, XR enables easier adaptation to the educational formula. Also, during lockdowns, an XR-based application can be considered a tool to promote socialization in the event. Thus, it enables to implementation of open and inclusive learning and teaching space, namely Edu-Metaverse. In the current social context, the obtained results provided valuable insights into factors affecting the users during the application of Metaverse in education processes, including remote learning. Finally, this paper suggests a research direction for the development of effective Metaverse-based educational solutions.

Keywords: Metaverse; STEM; Extended Reality; Education System.

RESUMEN

La educación es uno de los fundamentos esenciales del desarrollo sostenible de las sociedades y, en particular, de los objetivos SDG4 de la Asamblea General de la ONU. La Realidad Extendida (RX, el llamado Metaverso) permite la interacción multisensorial con entornos virtuales, objetos creados por ordenador y avatares. Además, el desarrollo dinámico de las pantallas montadas en la cabeza (HDM) permite una experiencia cada vez más profunda del mundo virtual, especialmente a través del desarrollo de la percepción de la profundidad, incluida la representación de varias modalidades como la visión, el tacto y el oído. Esto crea una oportunidad única para revolucionar el sistema de educación superior añadiendo una nueva dimensión de cognición y haciéndolo accesible a más personas, especialmente a las que viven en zonas de difícil acceso. También es un complemento perfecto para el proceso de educación de los estudiantes durante una pandemia, como la reciente pandemia de COVID-19. En este artículo, basándonos en la literatura y en nuestra experiencia, proporcionamos una visión general de la posibilidad de la aplicación del Metaverso en la enseñanza superior teniendo en cuenta las ventajas y limitaciones de los sistemas. Resultó que las soluciones basadas en XR pueden aplicarse con éxito en la enseñanza de la medicina, los cursos de química, así como en la enseñanza de la Ciencia, la Tecnología, la Ingeniería y las Matemáticas (STEM). Además, los sistemas basados en XR son útiles para el aprendizaje de habilidades espaciales como la navegación, el razonamiento espacial y la percepción. En el caso del aprendizaje a distancia, la RX permite una adaptación más fácil a la fórmula educativa. Asimismo, durante los cierres patronales, una aplicación basada en XR puede considerarse una herramienta para promover la socialización en el evento. Así, permite implementar un espacio de aprendizaje y enseñanza abierto e inclusivo, el Edu-Metaverse. En el contexto social actual, los resultados obtenidos proporcionaron valiosos conocimientos sobre los factores que afectan a los usuarios durante la aplicación del Metaverso en los procesos educativos, incluido el aprendizaje a distancia. Por último, este artículo sugiere una dirección de investigación para el desarrollo de soluciones educativas eficaces basadas en el Metaverso.

Palabras clave: Metaverso; STEM; Realidad Extendida; Sistema Educativo.

INTRODUCTION

In the second half of the last century, with the growing interest in higher education participation, these institutions became crucial both for the future of individuals and for social and economic development on a wider scale.(1)

Currently, higher education institutions (universities and academies) are perceived in Europe as a panacea that may prove helpful in overcoming the multidimensional crisis that Europe is facing.(2)

Therefore, various ways are used to encourage universities to educate graduates who will be innovative and competitive in the employment market. Together with contemporary economic challenges, the specificity and role of universities change, and they begin to act as engines of economic development.(3)

The 21st century has brought significant technological development, which, taking into account the above considerations, should be systematically included and used in higher education. In fact, technology has revolutionized practically all areas of life, including the education sector. Currently, two main technologies are affecting all parts of human life, namely Extended Reality (XR, the so-called Metaverse, and Artificial Intelligence (AI).(4)

Metaverse is created based on Web 3.0 technologies that were defined as open-source software, zero trust, and distribute interaction. Web 3.0 also used Artificial Intelligence.(5,6) It is also called the successor of the mobile Internet. The space of Metaverse can be fully virtual like Virtual Reality (VR), mostly based on interactions of avatars reflecting different personalities in the virtual world(7) or partially virtual like Augmented Reality (AR) or Mixed Reality (MR).(8) Another type of Metaverse is Lifelogging and Mirror World. Lifelogging is collecting, capturing, and storing information about users' daily lives.(9)

The commonly used Lifelogging is social media like Facebook, Instagram, and Twitter. Solutions using biometric information stored by wearable devices in medicine are also gaining popularity. The Mirror World is digital creations that mimic the real world, like for example, virtual maps and models using GPS technology or the game Upland, where users buy and exchange the virtual properties mapped to the real world. In fact, it reflects the real world combined with providing information about the external environment,(10) namely all objects and scenes are transferred as a reflection in the mirror. Metaverse enables user immersion through sophisticated three-dimensional (3D) graphics, advanced communication tools, and avatars.

Since Metaverse is defined as an open system, it required digital identities for both, real and computer-generated objects as well as mechanisms/tools for resource transfer and exchange.(11) Thus, Metaverse contains both augmented objects and mapped objects in the created virtual scene.(10)

Metaverse has a potentially wide range of applications, see figure 1a, in which the distribution of the Metaverse-based papers takes into account the subjects of application (based on the SCOPUS database) presented. In turn, figure 2 shows the distribution of the Metaverse-based papers taking into account the origin of publication general and during 2023 based on the SCOPUS database. In education, Metarverse is a quite new concept.(12)

It seems that it provides a great opportunity to create an open space where users can meet and interact socially, even without geographical limitations.(13) Avatars are a tool that gives users a sense of real presence in virtual meetings.(14) The main trend of scientific research (see figure 1a) is maintained considering the education sector, see figure 1b. As a result, three dominant thematic sub-areas of research lines have emerged, both in

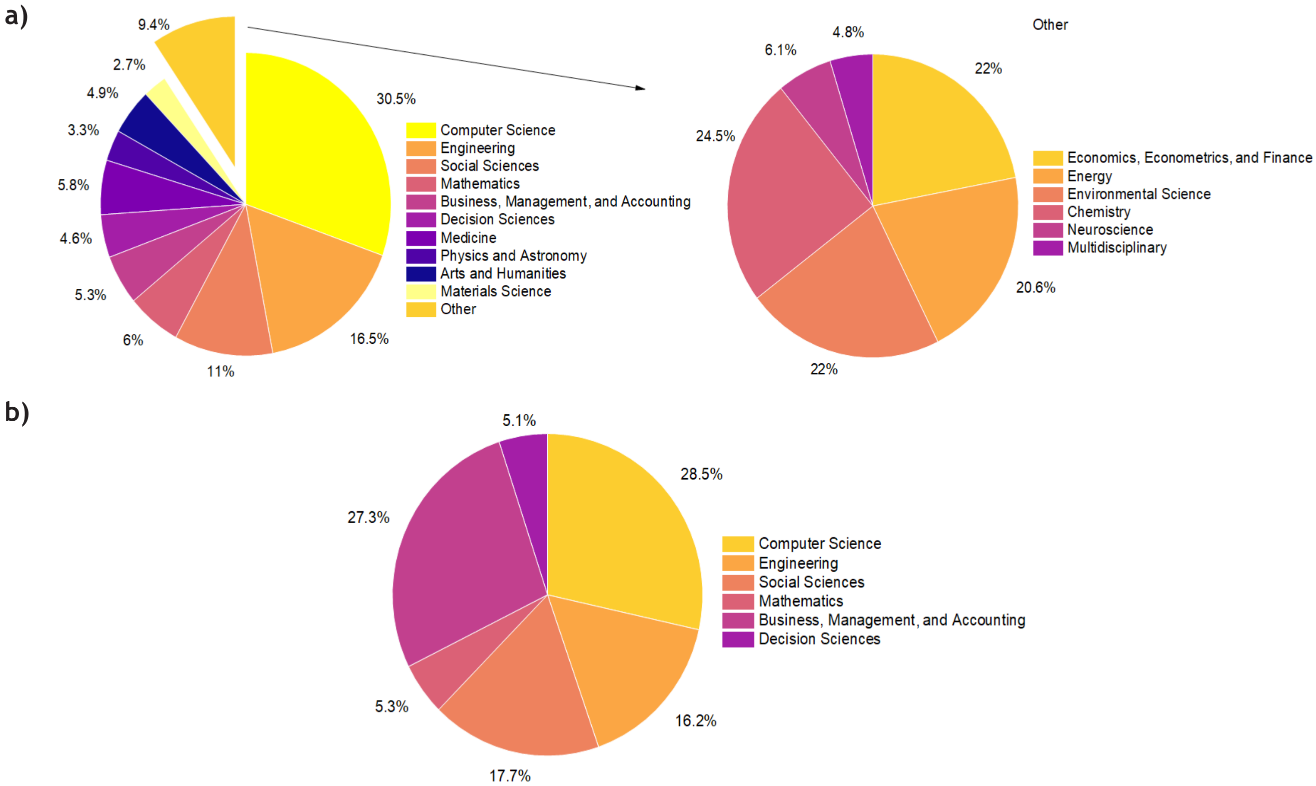

Figure 1. The distribution of the Metaverse-based papers takes into account divided into subject's areas (SCOPUS database) a) the subjects of application, and b) the subjects of application in the context of education

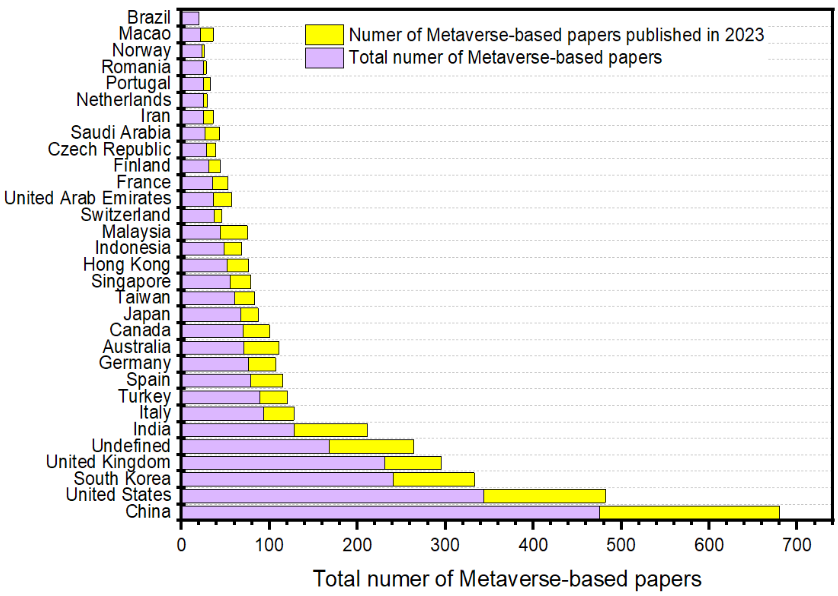

Figure 2. The distribution of the Metaverse-based papers takes into account the origin (SCOPUS database)

general and in the education sector. The first, dominant is Science, Technology, Engineering, and Mathematics (STEM), the second is medicine, and the third is management. In this paper, we will focus on the brief analyses of the first two areas as crucial to the effective implementation of the Metaverse in education. Our findings were confirmed by the analysis of the presented in,[(15)] however, this study contains only 81 papers.

The event that contributed to a significant acceleration of the implementation of the Metaverse in education was the COVID-19 pandemic.[(16)] From 2021, we observe a significant acceleration in the development of this technology compared to previous years. Certainly, there are still many questions and regulations that need to be refined before we fully implement solutions based on the Metaverse in the higher education sector. In this paper, we will analyze the advantages, threats, and limitations of implementing XR-based systems in this

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particularly important area for the future.

METHODS

The methodology of review methodology was based on the PRISMA Statement[17] and its extensions: PRISMA-S.[18] We considered recent publications, reports, protocols, and review papers from Scopus and Web of Science databases. The keywords: *Metaverse, Edu-Metaverse, education, higher education, Virtual Reality, Augmented Reality, Mixed Reality, Extended Reality*, and their variations.

The selected sources were analyzed in terms of compliance with the analyzed topic, and then their contribution to Metaverse. First, the obtained title and abstract were independently evaluated by the authors.

The duplicated records have been removed. Moreover, we have considered the inclusion of criteria-like publication in the form of journal papers, books, and proceedings as well as technical reports.

The search was limited to full-text articles in English, including electronic publications before printing. Also, the exclusion criteria like Ph. D. thesis and materials not related to Metaverse-based education have been adopted. Subsequently, articles meeting the criteria were retrieved and analyzed.

The documents used in this presented study were selected based on the procedure presented in figure 3. Finally, 86 documents were taken into account.

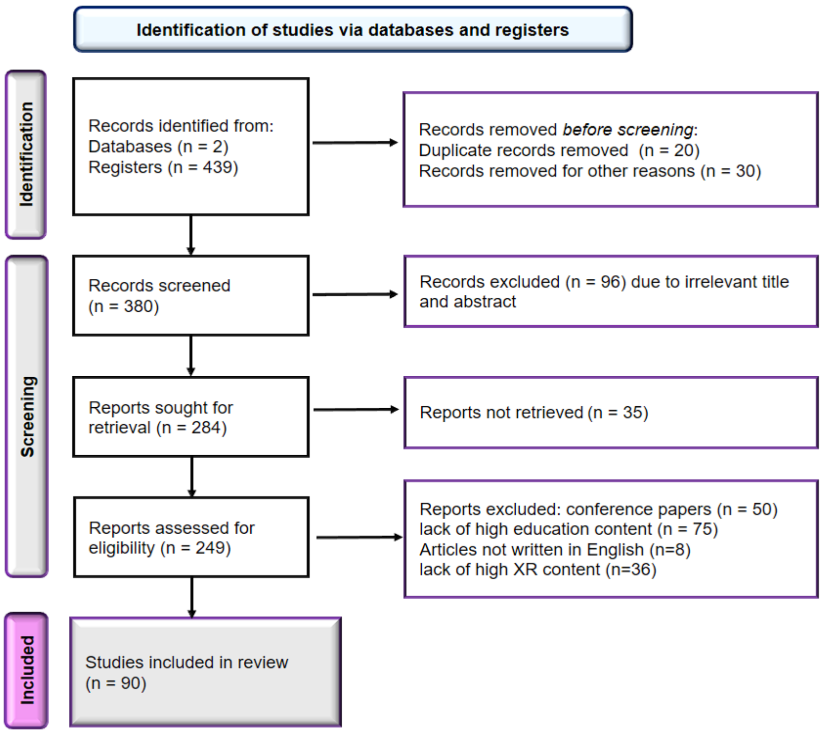

Figure 3. Literature search flowchart

RESULTS

Metaverse and Extended Reality in Education

Metaverse and Extended Reality in STEM

It is known that visual-spatial skills are correlated with academic performance, in particular in STEM, in which the understanding and ability to image spatial information is crucial. Metaverse can adopt this fact to the development of efficient learning systems for STEM students, including students suffering from poorer spatial imagination.[19,20] An example of the Metaverse-based support system in STEM is presented in Figure 4.

It stays in line with the core objectives of the Washington Accord the aim is to ensure the continuous improvement of professional teaching in the field of engineering [WA]. Education has been proclaimed one of the main foundations of the sustainable development of societies by UNESCO in engineering science and all areas of sciences [UNESCO]. The 3D visualization for the generation accustomed from an early age to using electronic devices makes educational materials more attractive and enriching.

Recently, Metaverse became increasingly used in various types of engineering courses.[21,22] In [23] VR was proposed as a support for mechanical technology courses. It helps students to understand the theory of introducing machine tool operations, however, did not allow them to develop their skills in operating these machines.

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This fact was probably due to the selection of the content presented during the course. An interesting study [24] shows the application of VR to the teaching process of safety in design. It turned out that the level of hazard understanding increased in subsequent stages of the course, however, students handled better at recognizing direct threats than threats requiring them to conclude. Also, roofing professionals found that the virtual simulators allowed them to better understand the problem of structural safety.[25]

Let's move on to civil engineering, learning how to construct buildings that would be resistant to various natural phenomena, including earthquakes, and hurricanes, is difficult for students and involves a lot of financial outlays. As a consequence, students rarely have the opportunity to participate in such activities. In turn, the Metaverse application can solve this issue.[24,26,27] For example, in [17] the students can create a virtual building and check its resistance to earthquakes. Metaverse can be also applied to university-level construction management courses, including project planning, sequencing, and scheduling.[28]

The results obtained, that VR helps students better understand complex concepts in the field of construction and locate errors faster. Metaverse can be also combined with Building Information Modeling (BIM) to enhance the design and construction changes in comparison to the original design.[29,30]

Metaverse can also be applied to the learning of medical chemistry. Recently, there has been a clear tendency to replace two-dimensional models of chemical structures with their three-dimensional counterparts for example, Web Browser-based applications, including VRmol[29] moleculARweb,[31] and ProteinVR.[32]

Such visualizations help users to understand the complex concept of chemical compounds and their structure. It is especially important during medical chemistry courses. In[33] the MR-based application of the 3D visualization of complex chemical compounds as point clouds or molecules was presented. Users can touch and actively interact with the displayed in HoloLens 2 structures. The structures can be rotated, observed from a different point of view, moved, and rescaled by the user's hand movements (i.e. gestures).

Other XR application fields in chemistry are the simulators of virtual laboratories.[34,35] They enable to assess the user's progress, taking into account the number and type of errors made by him and the time of performing individual tasks.[7] In [34] was shown that students of chemistry with low visual-spatial skills can improve them using XR systems.

Although only group mean scores improved significantly, these studies should be expanded to include more participants in the future. In[36] VR was adopted to the Raman spectroscopy course. It turned out that for most of the participants, i.e. 85,00 percent it was hard to get used to VR in such a short time, however, they see its advantages in longer use, after getting into the habit of using VR.

Figure 4. The scheme of the XR-based support system for STEM

Metaverse and Extended Reality in medical education and Healthcare

Both medicine and medical education are the areas that most willingly and quickly use technical innovations, including computer simulations, in particular, 3D visualization.[37,38] Thus, Metaverse creates the possibility of effective training of future medical staff, without potentially endangering the lives and health of patients, see figure 5.

It is possible by simulating real situations with patients, such as examinations, procedures, and operations, and recreating them using the program's active user participation.[33] Simulators applied in medicine are completely virtual or combine the virtual world with the real world.

As it turned out the Extended Reality provides a great IT tool for anatomy training.[39,40] For example, a VR-based simulator was applied to surgical training, especially laparoscopic procedures.[41] The proposed models include the Circle of Willis, Vertebral Aneurysm, Spine, and Skull are controlled by head tilts and gazes. Another virtual platform for anatomy training is 3D Organon [3Dorganon].

It enables to combined anatomy with ultrasound imaging. In turn, Stanford Virtual Heart is the virtual simulator of the heart that allows users to see a properly functioning organ, its exact structure, and blood flow, as well as the organ with various abnormalities and their impact on blood flow.

Thus, 3D Organon and Stanford Virtual Heart are addressed to medical students, medical doctors, academic staff, and patients [Stanford, UCSF]. They provide the tools for understanding, both human anatomy, including organ anatomy, and their abnormalities in the artificially created virtual world. The XR-based simulators can also combine the virtual and real worlds, like the HoloAnatomy® software by Case Western Reserve University and Cleveland [HoloAnatomy].

It is an MR-based training course, which contains holographic 3D human anatomy images, and approximately 9,000 3D models, divided into female and male bodies. It is worth noting that Metaverse was more often used by clinical teachers.(42) In turn, in the paper (33) the Mixed Reality-based solution to the root canal treatment, while in(43) to Vertucci's classification of dental root morphology. It is tailored to run the Microsoft HoloLens 2 glasses.

Thus, the Mr-base simulators can make students aware of the requirements for dental clinics.(44) Extended Reality-based simulators can be also applied to surgical training, while many simulators, such as pharyngeal surgery, have not been validated for surgery.(45)

Thus, the application of Metaverse to learning anatomy is more cost-effective than performing an autopsy due to the properties of "living organs", the availability of cadavers, the number of participants, time, and the possibility of repeating the procedure in the virtual world. Of particular importance here is the fact that there are significant differences between the anatomy of a living human and the anatomy of a corpse. This is due to the swelling of the soft tissues as a result of conservation processes.(46)

The use of XR-based technology in medicine shows better results in understanding taught content than traditional methods.(47) The XR-based solution in medical education can also be successfully applied to large-cohort.(47) Moreover,(48) showed that students that are learning with VR achieve better test exams, including pass rates than students that are learning tragically. It turned also that VR gives better results when using groups of students of any size.

The application of the XR-based simulators increases the increasing of students' understanding of the material and their learning satisfaction, even more than traditional medical training methods.(49) Thus, the transfer of the skills acquired by students to the clinical environment requires further evaluation.(50) On the other hand, it was also shown that Metaverse help improves students' communication and collaboration skills.(51)

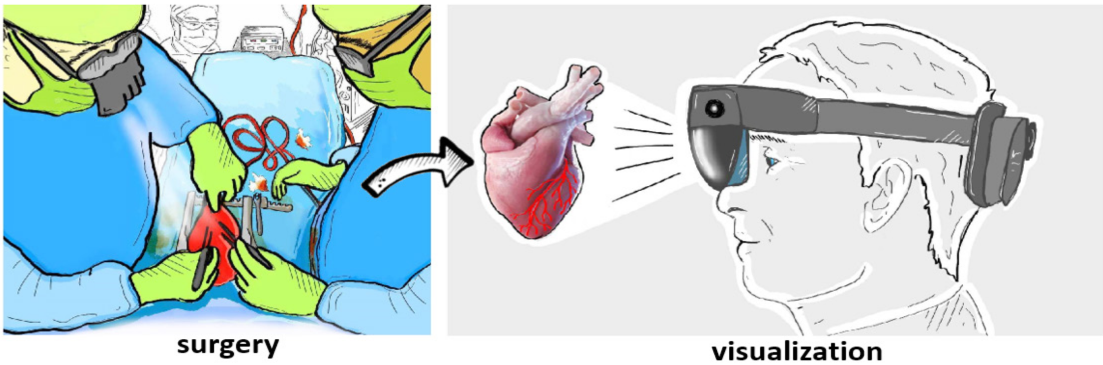

Figure 5. The scheme of XR-based support system for surgeons

Ethical Aspects of the Metaverse and Extended Reality

Metaverse technology is in constant development. It is essential to ensure a development that is compatible with respect for human and fundamental rights, freedom, and human dignity of so-called ethical design.(52) Thus, developing technical parameters combined with equality and diversity respecting ethical principles is a major challenge in designing the Metaverse.(53,54) In the virtual world may occur national, racial, religious, and gender issues.(55) It must be created ethical standards of behavior and content for the Metaverse(19,56)

On the other hand, faithful or sometimes even more attractive representations of the real world in the Metaverse may cause some users to be susceptible to reduced perception of physical space and disconnection from the real world. It should also provide the avatar with the ability to protect against harassment, a kind of boundary for the avatars of other users. Thus, the main ethical issues understood as a kind of moral philosophy in the area of Metaverse are user privacy and digital identities.(57,58)

Thus, the European Economic and Social Committee in April 2023 formulated calls for an ethical and safe metaverse for business and society.(59) In the field of scientific paper, the ethics of the Metaverse is a relatively new research area, the distribution of the Metaverse-based papers takes into account the context of the ethics war presented in figure 5. Fortunately, their number is growing, which gives hope that this key aspect will not be omitted.

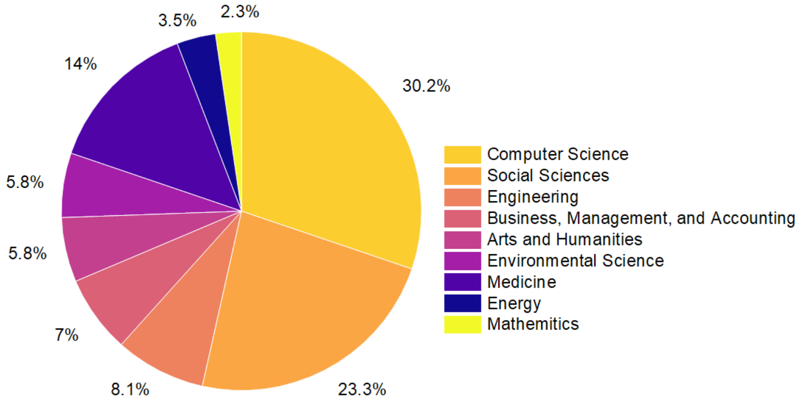

Figure 5. The distribution of the Metaverse-based papers takes into account the context of ethics

DISCUSSION AND CONCLUSIONS

Metaverse is an ITC tool that is very flexible in the process of creating learning environments. It creates an education tool that can be customized to the individual need of the students with a special emphasis on sensorial and embodied experiences.[(6)]

Education based on XR technologies has not been included in a rigid program framework at the moment, which translates into a variety of applications in teaching.[(15)] Metaverse allows for a more accurate assessment of students and their projects, taking into account problem-solving and critical thinking than traditional tests and exams, in which it is extremely difficult to assess these issues.[(58)] While a key element in the evaluation of education using the Metaverse is the comparison of the effects of traditional education with the effects of education using XR technology on a large group of students in various fields.

Thus, Metaverse-based education has many advantages, above all three-dimensional visualizations of materials with which the user can actively interact as, for example, MR, the ability to check the student's knowledge, the possibility of working in a group, availability at any time, such as VR simulators and accessibility at any location of users (teachers and students) - distance learning formula and direct interaction between the student and the teacher.

However, it must not be forgotten that nothing can replace human contact. From the social and practical knowledge point of view, it is challenging to replace this, even with the latest technology, in some professions. Moreover, it should be emphasized that, in situations where access to traditional education is limited, e.g., by the COVID-19 pandemic, Metaverse provides also a tool for sanitary safe continuation of learning.

Metaverse properly developed can be an amazing tool, currently, it suffers from several limitations. An important factor limiting access to technology is certainly its price (i.e. cost of HDMs) and access to the other powerful hardware as well as access to the high-speed Internet. Another limiting factor in studying the impact of the Metaverse on the higher education system is the lack of standardized metrics to assess the effectiveness of this approach compared to traditional methods.[(36)]

A certain technical limitation is also the auralization of the acoustics of a virtual room with six degrees of freedom. This requires providing a dense set of measurements of the spatial impulse response of the room. For example, in [(60)] the baseline interpolation method for higher-order Ambisonic spatial impulse response of the room was proposed.

Most solutions that use Metarerse in STEM education are based on a virtual mapping of the scenario of practical classes and laboratories.[(61)] The use of the XR-based system makes it possible to implement them in distance education. And thus limiting the exclusion of students with special needs (disabilities). Metaverse attracts remote learning students, however, their access to classes is limited by the disposal of HDMs.

The cost of purchasing the right equipment may be an insurmountable barrier for many students. Thus, limiting the cost of equipment always means limiting the level of immersion in teaching.[(62)] When it comes to students with physical disabilities, the Metaverse technology does not require them to stay in a standing position for a long time, and the interaction of avatars in the virtual world does not require much physical effort. However, as a technology based on the visual world, it may be unavailable to students with severe visual impairments.

In assessing the effectiveness of Metaverse implementation in the teaching process, the opinions of both students and professors/lecturers are important. An important issue is the assessment of the digital competencies of both groups. It turned out that the ideas about their digital competencies in the use of Metaverse of scientific staff are the same in the case of STEM and medicine.[(62,63)]

However, the awareness of competencies in the case of STEM professors influences the assessment of the usefulness of the Metaverse in the education process, and in the case of medical staff, the awareness of their competencies is not important. As a consequence of the professor's opinion, those educating students in technical faculties rated the aspects of the usefulness of Metaverse in education higher.

An interesting observation is the fact that STEM professors assess the technical and didactic aspects of this technology jointly, and professors in the field of medicine separately. It is worth noting that the opinions about XR-supported education of professors from private universities were significantly better than those of professors from public universities. Thus, the Metaverse should provide different opportunities for academic staff, while their needs are strongly dependent on the field in which they educate students.[64]

An important issue is also the in-depth opinion of the perception of the human body in virtual space by its users. The image of the body in virtual space can lead to changes in its perception and changes in attitudes. An interesting experiment was presented in the paper.[65]

Users of Virtual Reality take on two roles (two virtual bodies), one of them and the other of advisors, which was a representation of Dr. Sigmund Freud, alternately, until the participants of the study stopped. It turned out that VR users can develop a self-advice mechanism, but this fact still needs to be confirmed in brain imaging studies.

It is worth noting that the wide application of the Metaverse is connected with the high computation cost due to the cost of rendering high-quality 3D computer-created objects and scenes, and operating AI-based avatars.[66]

The avatar can take various forms, depending on the user's imagination and the technical capabilities of a given solution. Usually, avatars take the shape of people, animals, or creatures.[67] They must be able to reflect on people's facial expressions and emotions to make them more realistic. For example,[68] use face scanning to create avatars. On the other hand, technologies like edge computing, cloud computing, and distributed computing can be helpful during avatars and scene creation.[32]

This may be also helpful in storing and sharing resources by students and for students. Also, a new challenge for AI and partially for Metaverse has been defined, namely the carbon footprint of algorithms. While, the implemented algorithms consume large computing power, which is associated with huge electricity costs, and translates into the fact that they have a significant carbon footprint. This slowly translates into taking into account the energy parity in the calculations, thus reducing the carbon footprint.[56]

Thus, the user's interactivity is strictly connected with the technical parameters of the HDMs, in particular, haptic feedback adds to the realism of the Metaverse being felt. In this case, the development of brain-computer interface (BCI) technology is of huge importance, while the brain is the unit that controls all the human senses.

It is very likely that properly designed and connected to the human cerebral cortex BCI will lead to a deeper feeling of the virtual world.[69] The attempt in this direction is Neuralink.[70] Thus, Metaverse is a great opportunity to provide substantive changes in the higher education sector but also brings threats with it. ChatGPT can also have a beneficial effect on education, but ethical issues and potentially harmful effects must be considered.[71,72] There remains always the question of how far he can trust technology.[73]

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