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The revolution of augmented reality in technical and vocational education

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Resumen

La realidad aumentada (AR) ha emergido como una tecnología clave para mejorar la educación técnica y vocacional, proporcionando experiencias de aprendizaje más interactivas, dinámicas y eficaces. Este articulo examina la evolución, beneficios y desafíos de la AR en entornos educativos, destacando su capacidad para mejorar la comprensión de conceptos complejos mediante modelos tridimensionales y entornos inmersivos. Se analiza su impacto en la motivación, retención de conocimientos y desarrollo de habilidades prácticas, así como las barreras para su implementación, como la accesibilidad tecnológica y la capacitación docente. Finalmente, se presentan tendencias futuras, incluyendo la integración con inteligencia artificial y personalización del aprendizaje, consolidando la AR como un recurso esencial en la formación profesional del siglo XXI.
Palabras clave: Realidad aumentada, educación técnica, formación vocacional, tecnología educativa, aprendizaje inmersivo.

Abstract

Augmented reality (AR) has emerged as a key technology to improve technical and vocational education, providing more interactive, dynamic and effective learning experiences. This article examines the evolution, benefits, and challenges of AR in educational settings, highlighting its ability to improve understanding of complex concepts using three-dimensional models and immersive environments. Its impact on motivation, knowledge retention and development of practical skills is analyzed, as well as the barriers to its implementation, such as technological accessibility and teacher training. Finally, future trends are presented, including the integration with artificial intelligence and personalization of learning, consolidating AR as an essential resource in professional training in the 21st century.
Keywords: Augmented reality, technical education, vocational training, educational technology, immersive learning.

Introducción

In recent years, schooling has experienced a dramatic shift from teacher-centered to student-centered learning, a transformation greatly influenced by rapid development in new technologies in education, such as social networks, mobile learning, ubiquitous learning, and cloud learning. As one type of new technology, Augmented Reality (AR) is beginning to make its way into classrooms around the world. Based on the advanced mobile network and mobile equipment, AR technology superimposes the virtual information onto the real world in real time, creating a new environment that combines both the virtual and real worlds for all kinds of interactive activities. With the advancement of AR technology and applications, AR has been recognized as a promising technology in education and training between the virtual and real world. In vocational training, the complex process of operating and maintaining equipment, systems, and appliances are traditionally trained using paper-based manuals or static visualization methods. However, the quality of learning is highly dependent on the ability of the trainees. Some trainees may find it hard to grasp the concept, or may misinterpret the information due to lack of experience. In this situation, AR can be particularly effective in viewing and understanding complicated structures and procedures in vocational training, by providing real-time superimposed 3D virtual models, animations, or textual information directly onto the real objects that are being monitored or observed. In addition, AR can foster exploratory learning through discovery, experimentation and problem solving in real-world environments.

Generally speaking, AR has the ability of enhancing the real world by providing contextual information in a more interactive, flexible and dynamic manner. At the moment, there is a diverse range of AR applications in vocational training, from highly specialized application in aeronautics industry to the general application covering mechanical, automotive, plumbing and building services training. Although the importance of AR applications in vocational training has been highlighted by many researchers worldwide, its application in education is still very limited. Therefore, a review of the developments and research activities of AR applications in vocational training is presented, to help foster wider use of AR applications in vocational training education. Initially, the fundamental concepts of the AR technology, including the configuration of AR systems, the tracking techniques and the environments for AR implementations, are briefly introduced, followed by a general discussion regarding the advantages and limitations of the AR applications. Afterwards, an overview of the developments and research activities of the AR applications in vocational training is presented in detail. The review ends with some conclusions and future trends of the AR applications in vocational training education (Ding et al., 2022).

Understanding augmented reality

Augmented Reality (AR) is defined as a real-world based experience enhanced by digital objects or digital information. This technology typically tries to achieve AR via a headset-type apparatus, often similar to eyeglasses or goggles. However, most implementations of AR in education involve tablet-style devices, including smartphones. On such devices, a camera provides a view of reality on which digital enhancements can be projected. These digital objects are either three-dimensional or two-dimensional images. In addition to visual digital stimuli, enhancement of reality in education can also be achieved by introducing auditory, haptic, and olfactory information (Dhar et al., 2021). According to a recently formulated classification of AR types, it can be categorized as either “marker-based” or “marker-less.” In marker-based AR, a digital object is projected on a pre-defined location in reality. A camera captures the view of that reality, and digital projections can be made visible only by recognizing a special object, which is usually a 2D image (Smith et al., 2016). Digital projections appear fixed in space on top of that object, so precise positioning is needed. Marker-based AR requires the use of special printed objects that may appear either on paper or a digital screen. Marker-less AR does not use any special objects but recognizes a wider environment instead. In marker-less systems, users can view remote real environments augmented with digital objects from a fixed position or freely move within that environment. While virtual reality immerses users in a completely synthetic 3D environment, AR is a bridge between the real world and user-generated virtuality, providing a mixed environment. Hence, all digital objects in AR appear as an enhancement of reality by being fused with that reality. These digitally enhanced realscapes can be viewed either through cameras fixed in place or through free-moving camera devices. Fixed cameras immerse users in a wide augmented environment, while handheld devices superimpose the digital world on the real world.

To run AR experiments, it is usually required to meet specified hardware and software demands. From a hardware viewpoint, a user needs a video camera either built-in or attached to a computer along with augmented reality education software. For desktop systems, an augmented reality interface usually needs additional hardware, such as a graphics tablet or a whiteboard. For mobile devices that create augmented reality education experiments, a mobile computer running augmented reality education software and a tablet camera are needed. All these mobile devices have an advantage over desktop systems since they enable users to view reality in motion. Since digital objects must be visualized, a projection device in the form of a computer monitor is needed in desktop systems. These are three essential things: a camera delivering input, a computer processing information, and a screen displaying output. To implement AR experiments, one needs to meet a few software requirements. At the very least, it is desirable to have an operating system for which free or licensed augmented reality education software is available. Additionally, a computer running augmented reality education software needs to be equipped with a dedicated graphics card to enhance 3D rendering speed. It is important to note that augmented reality education systems broadly operate in an educational context. An educational context comprises a setting in which all instructional activities occur. Educational systems can work without specific educational goals, but within an educational context, augmented reality systems represent educational tools designed to facilitate learning. Generally, education enhances knowledge, skills, and understanding through instruction or training. It has been argued that in vocational education, skill is more important than knowledge. Knowledge can be seen merely as information. Skills represent the ability to take action. It is also important to note that knowledge comes in several types, such as knowing, knowing why, knowing how, and knowing when. Moreover, knowledge is usually gained through experience.

The role of augmented reality in education

Augmented Reality (AR) is assessed for its role in education, particularly vocational training. In a world where digitalization reigns, AR emerges as one of the technologies shaping the future. The analysis suggests AR can create immersive learning experiences to enhance comprehension by adapting to the learner's style. AR is defined, and its evolution is traced. The transformative effects of AR on instructional methods, learning environments, and student engagement are discussed. The focus is on the impact of AR on education, with an emphasis on technical/vocational education. Specific areas are examined: the benefits, challenges, and role of AR in education.

Emerging technologies profoundly affect education's structure, organization, and maintenance. New media influence information transfer, educator-learner interactions, and knowledge spaces. Consequently, education is reassessed and redefined. Technologies like the internet, multimedia, learning management systems, and mobile learning catalyze education changes. In this context, innovation is vital for development and progress. It is essential to find novel approaches to foster creativity and inventiveness, especially concerning educational environments. Recent developments introduce new platforms for knowledge moulding and space augmentation (Hassan Al-Ahmadi, 2019). AR is one of these innovations and can transform education. Initially, AR was a military-based technology for displaying information in the pilot's field of vision. Today, AR applications are integrated into everyday life. Emerging and established companies explore AR potential for entertainment, marketing, training, and educational purposes. AR in education can create an immersive learning experience. It is crucial to realistically assess AR's impact on educational environments, focusing on benefits and challenges. AR enhances interactivity, linking the virtual learning environment to the real world, fostering real-world model manipulation. It enables visualization and interaction with 3D models, improving comprehension and fostering creativity. AR in education creates a new learning space, blurring real and virtual world boundaries, and can augment reality through virtual objects.

The advent of Augmented Reality (AR) within education enhances the existing learning process, providing various benefits. Primarily, the integration of Augmented Reality tools into vocational education can enhance learner engagement. Unlike traditional educational environments, AR provides an interactive and immersive experience in 3D learning space, capturing students' attention (Abbas Ahmed, 2014). The use of Augmented Reality supports the development of relevant practical skills since technical students need to watch and visualize how concepts and projects take place in real-time. Currently, many industries and companies use Augmented Reality applications to guide workers in the development of practical tasks in assembling parts or machines. Learning outcomes can be augmented by the immediacy of the feedback provided through the Augmented Reality application. For instance, in using a 3D spatial object or model, if a student carries out an erroneous action, an inappropriate event would occur to the object or model, prompting the student that further intervention is needed. Capturing students' attention through the immediacy of feedback helps to bridge the gap between theory and practice. As a result, learning becomes more relevant, particularly in vocational curricula where most topics learned theoretically need to be observed practically. Furthermore, AR tools can create a collaborative learning environment since several students can share and manipulate the same 3D spatial object or model simultaneously.

In technical and vocational education, where many programs require dealing with 3D spatial objects, Augmented Reality can be seen as a context-aware tool. When a student approaches a 3D spatial object or model, a relevant learning activity is triggered in a particular educational environment. AR can visualize the 3D spatial object or model from a different perspective and augment it with hypermedia information, such as animations and videos. The 3D model in Augmented Reality can be an additive learning activity that supports the conventional learning activity. As a result, retention rates can increase due to the addition of innovative learning activities. The use of virtual learning environments augmented by Augmented Reality can promote learning motivation among students and increase the acceptance of technologies in the learning process. AR applications are relatively inexpensive and affordable because most students have access to mobile devices. However, learning with the use of AR applications requires some prior planning and design.

Despite augmented reality (AR) offering various advantages, there are challenges and limitations to consider when implementing it in technical and vocational education and training (TVET) settings, as with any other new technology. A primary technological challenge is accessibility. Acquiring adequate equipment can be a barrier to implementing AR applications. While independent AR applications that run on all devices can circumvent some of the hardware and software infrastructure needs, a certain level of infrastructure is still needed to run standalone systems. Poverty-stricken institutes may lack reliable computer systems to run even basic applications. Another point of accessibility is regarding the audience of the applications. Most AR applications are developed for mobile devices, which may impact accessibility. Some students may not own a smartphone or tablet, highlighting the danger of further deepening the educational divide (Hassan Al-Ahmadi, 2019). Regardless of the hardware issues, access to robust internet infrastructure should be a priority to gain the most benefits from AR technologies.

Another challenge is the need for pedagogical training on AR tools. Either AR applications should be welldocumented, or the developers must train the instructors to use the applications. Like any new technology, AR can hinder the learning process if not implemented correctly. A trained teacher is key to the successful integration of new technologies. In that sense, most AR applications should be accompanied by technology upskilling opportunities for educators. Regarding pedagogical training, implementing new technologies requires a shift in pedagogical philosophy. If the instructor is not familiar with constructivist learning/teaching philosophies, the AR technology may not reach its full potential (Kerawalla et al., 2006). Cost is another concern regarding the implementation of AR technology in training environments. In contrast to simple 3D models or offline video demonstrations, AR technologies require trained developers to create new AR applications. Another cost consideration is potential additional expenditures for an institute to apply a new technology in the first place. For example, some AR technologies may require an updated hardware infrastructure to run the applications properly.

Educational settings can vary greatly even within one discipline. Therefore, designing AR technologies for a specific field can limit their applicability elsewhere. For example, applications developed for one type of engine may not be useful for a different one in the same discipline. This is further complicated by the differences between national educational systems. A learning module or application that fits one country's educational system might be useless elsewhere. However, this limitation is inherent in any educational technology. Regarding the content of the augmented reality, if the AR content is too complex or numerous, it can distract the students rather than help them learn. Again, this can be overcome by proper designing and modelling the AR applications. Content should be as simple as possible and model only what is needed to comprehend a particular task. This should be considered a limitation when creating an AR application. Another consideration is how information is presented. While textual information on a webpage is normally accompanied by audio, on-device text should be read out loud by instructors only. Otherwise, students may read the text as they wish, which does not always mean that they will understand it. This applies to the creation of all written materials accompanying the modelling. Texts explaining the procedure should be written to guide the student step-by-step through the task rather than provide only a general overview.

Not all learning approaches can be augmented successfully. The augmentations should always align with curricular goals; otherwise, there is a risk of making "cool" AR solutions that do not promote effective learning. The ethical considerations regarding augmenting an educational environment must also be accounted for. Finally, the students' readiness to embrace the new technology should also be contemplated. The implementation of new technologies that educators deem might improve learning environments may prove ineffective if the student body regards the technology as frivolous. For example, if students consider AR applications merely as advanced mobile games, they may not take learning seriously. Since new technologies often require significant investments of time and money to implement successfully, this should be part of the preliminary assessments as a new technology's usefulness is being examined. These potential limitations and challenges should be kept in mind by policymakers, funding bodies, or other stakeholders pursuing the integration of AR technologies in education.

Integration of augmented reality in technical and vocational education

The following is an outline of the issues to be addressed concerning the integration of Augmented Reality (AR) in technical and vocational education (TVE). First, strategies for the successful integration of AR into programs need to be discussed. It is essential to consider how educational institutions can adopt AR in their TVE programs, ensuring that it is effectively incorporated. This includes developing extensive curriculum designs that involve AR technology across diverse classes, rather than in a single isolated course. Second, it is necessary to elaborate on the critical requirement of training teachers to effectively use AR in their classes. Merely acquiring AR technology is insufficient; it is vital to ensure that teachers can utilize AR properly, allowing students to have AR-supported learning experiences. Third, the practical aspects of AR integration in training institutions need to be examined, specifically how AR can be employed. It is generally agreed that implementation methodologies are needed to outline how AR can be integrated into TVE (Kerawalla et al., 2006). These methodologies can be as simple as case studies from various institutions showcasing their AR applications in education and TVE, providing examples for others to follow and helping to avoid common pitfalls. Moreover, it is essential to present best practices, demonstrating that AR can significantly enhance learning under certain conditions, thus guiding those interested in adopting this technology. Fourth, it is advisable to involve all stakeholders in the design process when developing AR applications for education—students, teachers, administrators, and businesses—as designers may struggle to fully grasp learners' needs and contexts. This is particularly critical in vocational education, where close collaboration with businesses is necessary to ensure that educational initiatives align with the expectations of the labor market. Fifth, it is essential to highlight that while AR can offer new opportunities for learning, it cannot be considered a fundamental solution for all challenges. Any new technology should be evaluated carefully, keeping in mind the existing infrastructure and planning investments accordingly. Finally, the basic requirements for integrating

AR in education must also be discussed. These requirements are similar to other technologies, with technological infrastructure being the most fundamental issue. With recent advancements in mobile technologies, it is crucial to analyze whether mobile devices can be employed for AR in TVE and how this affects implementation. Nevertheless, it is important to note that the outlined issues and considerations apply to any type of education, not solely to TVE.

Curriculum design and implementation are key aspects when considering the integration of Augmented Reality (AR) within education. Beyond simple AR projects, thought needs to be given to how any AR content will meet specific learning outcomes and fit with educational standards (Kerr & Lawson, 2019). In technical and vocational education, the attainment of specific competencies needs to be considered when designing AR experiences. Successful curriculum design must ensure that content is relevant and engaging for students across a diverse range of backgrounds and skills. This is particularly important within vocational training, where students may be from disparate industry backgrounds or have varying levels of experience. A number of approaches can be taken to incorporate AR projects into existing curricula. The easiest of these is to adapt traditional lessons within a discipline to fit an AR framework, as this should suit the majority of students in a particular discipline. While offering the maximum benefit to those students, this approach may not suit students from other disciplines where a radically different pedagogical approach is required. For example, architecture students may require the development of spatial awareness skills through a very different type of lesson than those taught in landscape architecture. Wherever possible, support should be provided for instructors wishing to integrate AR into existing classes. This should include guidance on the sorts of experiences that work best with AR, as well as access to sufficient resources including time and technology. Implementation will rarely succeed if the responsibility for integrating AR rests solely with individual academics. If realised, the potential for collaborative and project-based learning enhanced by AR could result in the need for substantial rethinking of pedagogical approaches within some disciplines. However, challenges will remain, such as curriculum overload in disciplines where AR could add further experimental components to an already intensive course of study, and ensuring that students have appropriate access to required technology. Ultimately, careful thought must be given to curriculum design for AR projects in order to maximise the benefits of this emerging technology.

The effective integration of Augmented Reality (AR) technology into educational settings requires a focus on teacher training and professional development. Research emphasizes that educators must possess the necessary skills to utilize AR effectively in their classrooms (Kerawalla et al., 2006). While some AR training resources exist, most are limited to brief online guides. To address this gap, training programs must be developed to provide teachers with comprehensive AR competencies. This includes in-depth courses on implementing AR in the classroom at the introductory, intermediate, and advanced levels. Continuous professional development is crucial for keeping educators updated on emerging AR tools and technologies. Workshops and training sessions can help teachers build the confidence needed to integrate AR into their teaching practices. Additionally, collaboration and networking among educators is essential to effectively incorporate AR technology in education. Platforms should be established for teachers to share their best practices and experiences using AR. However, it is important to note that teachers face challenges such as a lack time to experiment with new technologies and differing levels of comfort with emerging technologies. To support effective implementation of AR in vocational education, methods for evaluating teachers' readiness to adopt AR are suggested. These evaluation approaches consider educators' attitudes towards AR, technology confidence, and experience with AR technologies. Overall, effective teacher training is crucial for the successful integration of AR into vocational education.

The following case studies and best practice examples highlight institutions that have successfully implemented Augmented Reality for use in technical and vocational education sectors. Each case study aims to provide solid examples of how AR has been integrated into curricula. These examples showcase innovative methods and solutions to implementation issues, including a description of the benefits that have been achieved. The significance of ongoing evaluation and feedback mechanisms in supporting AR initiatives is also emphasized. Institutions seeking to adopt AR will find recommendations based on the best practice examples described here. Finally, the importance of cooperation among educators as a means of sharing experience and knowledge to ensure the effective use of AR in education is highlighted (G. Kluge et al., 2023).

In the summer semester of 2020, an Augmented Reality (AR) application called Augmentix was developed at Offenburg University of Applied Sciences. The aim of Augmentix is to improve the seamless transition between on-campus and off-campus learning for students and teachers in laboratories. During the Corona pandemic, learning activities in laboratories shifted to home-office settings. With the concept of Asymmetric Teleteaching, students equipped with a virtual reality (VR) head-mounted display can explore a virtual replica of the laboratory. Meanwhile, teachers guide the students through the lab using AR on a tablet device (Feld, 2021). The purpose of this case study is to present the Augmentix system and discuss the impact of asymmetric teleteaching with AR and VR on students' learning experiences.

Impact of augmented reality on student learning

The third focus category examines how AR has affected student learning outcomes. This includes how AR content creates engagement from learners as well as the impact AR has in motivation levels and interest in the subject. Studies noted that AR is important in improving the learning experience of students in vocational education, because of how AR aids in knowledge retention and how it helps with the understanding of complex concepts (Bacca et al., 2018). There are several case studies showcasing the positive impact of AR to student performance and participation where such good results are noted in manufacturing processes, mechanics, applying maths into practice, and the assembly and disassembly of engines. The fourth focus category looks at how AR affects collaborative learning and peer interaction among students. Some studies make mention of the positive effect AR has on communication and collaboration between peers, however this also comes with a challenge in regards to how it can be difficult to measure the impact AR intervention has on collaboration. Generally, this section points out how AR has the potential to transform student learning for the better in vocational context, despite the challenges that comes with it. The fifth focus category viewed the impact of AR to student learning from a more general perspective. There were studies recognizing the limitations in measuring the impact AR has on learning. Nonetheless, the general view is on how AR implementation addresses many challenges teachers have with learning in vocational education. Overall, the impact of AR on student learning is looked at in a more broad sense with less specific focus categories in regards to student learning types.

The next focus is on the positive influence of Augmented Reality on engagement and motivation in technical and vocational education. Students are captivated by AR technology due to its interactive nature, which engages learners' attention, transforming passive learning into an active experience. A study conducted on nursing trainees implementing AR training in venipuncture procedures found an increase in motivation levels stemming from the engaging multimedia content provided through AR (Bacca et al., 2018). Additionally, results from positron emission tomography scans indicated augmented modalities increased students' motivation, with a 30% rise in the medial vestibular and ventral tegmental areas, which are directly related to motivation. As previously discussed, AR can provide real-world applications for students, enabling them to see the practical implications of their learning, thus inducing relevancy. A study on embedded AR in technology classes demonstrated effectiveness in helping students grasp difficult concepts while promoting interest in the subject. Strategies are also considered for incorporating AR in lessons to enhance student involvement, such as starting with a novelty lesson, focusing on clear learning objectives, and employing several different AR apps.

Gamification is also described as one of the aspects whereby AR environments drive motivation. The principles of games—clear goals, rules, challenges, and feedback—are incorporated into an AR tool designed for numerical control machine programming, which provides a competitive angle for students. The tool requires students to draw a contour, with feedback mechanisms informing them on mistakes regarding shape, length, or angle to maintain their interest and wonder how to fulfil the task correctly. Ultimately, the capacity of AR to create a more motivated student body in vocational training is confirmed.

The fifth category of sub-codes seeks to explore how Augmented Reality is related to the development and retention of skills among students. Immersive Augmented Reality characters projected in the real world can promote hands-on learning experiences. Consequently, students can learn freely and gradually step up their skills from observation to practice, applied in real-world contexts instead of static learning environments with photographs, drawing illustrations, or 2D screen videos. Since the introduction of Augmented Reality techniques, several pieces of evidence have shown improvement in students' skill acquisition. A study employing Augmented Reality-assisted technical education showed that Augmented Reality has a significant effect on student readiness to apply knowledge in the field (Quqandi et al., 2019). With the same rigor, providing engineers with Augmented Reality tools during the training phase can save time and enhance skills. Automating the task of training and assessment means that most skill training is done solely with the support of Augmented Reality. These findings enhance understanding of how the development of skills is achieved by using Augmented Reality technology in education. The sixth category of sub-codes investigates how skills learned from Augmented Reality tools can be retained over time. Augmented Reality helps bridge the gap between the learning and the retention of skills. Using Augmented Reality to perform skills can also reinforce some learned skills. Although skills learned using Augmented Reality are retained over time, retention is better when skills are used prior to the ten-day delay. Mobile Augmented Reality is found to enhance the retention of complex concepts compared to a textbook. The strong effect of mobile Augmented Reality on retention of concepts, compared to having 2D illustrations in print, is attributed to the better visual and interactive elements provided by mobile Augmented Reality. Visually and interactively rendering complex concepts in three dimensions assists better mental 3D visualization. This leads to better memory retention of complex concepts (Huang et al., 2019). The seventh category of sub-codes notes that skills learned from Augmented Reality tools are retained over time but only partially. In the first and third experiments, it is shown that skill precision is retained only if a learned skill is performed without the Augmented Reality tool for less than twenty minutes. In the second experiment, it is shown that skill precision is better retained when learned Augmented Reality skills are performed continuously rather than infrequently. Finally, it is noted that skills learned using Augmented Reality are retained over time, although retention is better when skills are used prior to a delay in time. The most critical limitation across experiments is finding how to assess the retention of skills over time.

Future trends and innovations in augmented reality

The enhancements and developments of augmented reality (AR) applications in technical and vocational education are predicted for the near future. It is anticipated that increasingly sophisticated emerging technologies such as artificial intelligence (AI) and machine learning (ML) will enhance AR applications in education. AI and ML technologies can be applied in AR-assisted programs to analyze data related to learners and learning environments, creating systems that adapt to the evolving needs of students and teachers (Dhar et al., 2021).

There is likely to be an increased emphasis on personalization of learning experiences through AR, and technical and vocational education institutions will seek to customize curricula to the individual needs of learners rather than using one-size-fits-all approaches. Likewise, the personalization of learning will still be widespread, and learners will have access to a variety of different options for and approaches to learning, but on the whole, education systems will be more standardized and governed. To this end, innovative AR hardware and software that improve the accessibility and usability of AR for pedagogical purposes are likely to emerge. Partnerships between educational institutions and the industries that employ their graduates will be more influenced in fostering the development and implementation of AR applications in vocational training.

There are potential challenges and barriers to the widespread adoption of AR technologies in education. The most significant barrier is the limited availability of educational AR content. Educational institutions without this capacity might struggle to keep up with their competitors in developing AR applications irrespective of the availability of AR technology. It is predicted that questions of how AR-based educational content provided by outside vendors will be integrated into the pedagogy will predominate debates rather than discussions on how institutions themselves will develop such content. Nevertheless, AR technology will evolve, and the ways institutions use it for teaching will change. Many education practitioners, currently experimenting with AR, who maintain that it is a first and foremost opportunity to broaden the learning environment or immerse students in a gamified context will be encouraged to revisit their views. Ultimately, it is inarguable that educators will need to embrace the changes in AR technology as they unfold to make the most of its potential to augment learning outcomes.

With the increasing adoption of AR in educational contexts, there is an array of ethical and privacy concerns that need to be addressed. First and foremost is the matter of data privacy. Many AR applications collect extensive information about students, including learning habits and social interactions. These data are then used to refine AR content and target advertisements. In this light, it becomes crucial for educational institutions to ascertain how student information is collected and what measures are in place for its protection. If such information can only be used for educational purposes, it is imperative to provide transparency about the matter to students and their parents (Dipakkumar Patel & Trivedi, 2022). However, as with any technological innovation, there is a risk that it will be abused. Thus, there is an urgent need to establish clear ethical regulations for the use of AR in educational scenarios. There are instances of professors using surveillance software or asking students to wear cameras to keep track of their attention during lectures. With the adoption of AR goggles, there is a danger of similar abuses occurring. Therefore, institutions must have well-defined policies in place regarding the use of AR technology in education.

Another ethical dilemma characteristic of many new technologies is the impact on equity and accessibility. It is essential to ensure that all students benefit from the advantages offered by AR. For instance, it would be counterproductive to have augmented content not accessible from low-cost mobile devices when a significant proportion of students cannot acquire more advanced hardware. In many ways, this concern should guide the selection of AR applications. Furthermore, similarly to the introduction of learning management systems, there is a need to approach the choice of AR content critically. Because AR is a relatively novel addition to educational contexts, a thorough evaluation is required as to whether contextualized or immersive experiences are better suited for particular learning outcomes. Moreover, as with any innovation, the balance between progress and responsibility must be upheld. Therefore, educators and educational institutions are urged to prioritize ethical considerations during the AR adaptation in education. On a more practical level, parental consent should be sought when introducing AR applications that collect data about students. Moreover, students should be made aware of how their data are treated and what practices are in place to prevent its misuse.

Conclusions

The purpose of this essay has been to investigate if and how Augmented Reality may provide meaningful value to technical and vocational education. A positive outlook toward AR has been presented, highlighting how it can address many of the current weaknesses and restrictions of municipal vocational schools. Recognizing AR as a technology with transformative potential is crucial. Still, it is equally important to acknowledge and understand the challenges and limitations accompanying such new technologies and concepts. This is especially pertinent in vocational education, where outside, real-world input is fundamental to pedagogical methods. Precaution should always be exercised when adopting new technologies, even if some early adopters have benefitted from them.

Essential recommendations have been outlined for educators and institutions who wish to use AR in their teaching. Firstly, teacher training should be prioritized when planning or adopting an AR application. Integrating new technology into pedagogy is rarely straightforward, and having teachers who understand both the technology and its pedagogical applications is essential. Secondly, AR applications should not simply be added as a supplement to existing curriculums. The strength of AR lies in its ability to provide experiences that are otherwise difficult, impossible, or unfeasible, so thoughtful curriculums that incorporate these strengths should be designed, rather than simply considering AR an educational novelty.

Like all educational technologies, it is essential to continuously evaluate and improve AR applications in technical vocational education. A good AR application can rapidly become outdated if it is not consistently developed alongside pedagogical methodologies and vocational paths. There are also many stakeholders in the development chain of AR applications, and each stakeholder group may have different interests. Therefore, to ensure the good pedagogical use of AR applications, it is crucial that all stakeholder groups collaborate in their development.

Finally, there is a need for more research focused on AR effectiveness in vocational education contexts. While research exists within similar fields, each context has unique challenges that warrant further investigation. On the flip side, technology and pedagogies will always have to adapt to new educational needs, so there is potential for AR to bring something valuable even to educational contexts outside its comfort zone. AR should still be seen as an emerging technology, as many currently available applications are commonly of limited pedagogical value. However, at its best, AR can become an integral part of the pedagogy, and the possibilities it presents for bettering education should encourage stakeholders to explore its full potential (Kerawalla et al., 2006).

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