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eXtended Reality and Accessibility in Online and Distance Learning: Exploring the Opportunities and Challenges

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Abstract. Novel eXtended Reality (XR) learning activities are being introduced, planned, and explored in teaching at many, if not most Higher Education institutions. However, there are widespread concerns regarding how these innovations can be used in ways that are accessible and inclusive. A lot of questions are being posed, and only parts of the answers are available. Within this contribution, we review opportunities and challenges associated with XR learning in the more narrow field of Online and Distance Learning (ODL). ODL is the EdTech sector which, through its challenges of 24/7 and global availability, often pioneers technologies ready for the mainstream. For this, we first provide an overview of accessibility needs in a diverse student population, focusing on disabled students), to then review the legal and regulatory context which frame the obligations of institutions. We reflect on what already exists and on potential contributions to the development of XR and its use by all. We introduce three heterogeneous examples to illustrate the use of XR learning in ODL, to then describe how legal and regulatory obligations translate to the institutional context. We discuss gaps and open problems, and outline future work possible.

Keywords: XR, Accessibility, Online and Distance Learning.

1 Introduction

It remains a conundrum why any technological innovation first becomes exclusively available to a select few, before widening its reach to a more diverse range of users. This is why we often get models and approaches wrong in the first instance, fitting solutions to the needs of closed circles of developers or preview audiences, and forgetting about the exigencies of the many.

eXtended Reality (XR) is no exception to this, and while guidance, regulation, and best practice for accessibility progresses for information technology at large, its translation to XR seems to be lagging. One reason for this lag is the difficulty of translating existing solutions to a technology still in its infancy, with its kinks not yet worked out, and the sector-independent 'dominant designs' not yet available. Often, fixes will emerge from those domains where they are most needed, or where there is a legal obligation to uphold. For XR accessibility, this is undoubtedly the education sector, where the state has the duty of care for its citizens to enable them to partake in learning on all levels. Within education, technological innovation typically first arrives in distance learning, as the very nature of the work demands adaptation, and integration of digital tools, to diverse learning environments.

As such, we are investigating the current situation regarding XR technology and accessibility, with a focus on online and distance learning. Our aim is to inform and motivate further research by considering the developments we expect to impact the XR sector as a whole in the near future. We seek to identify the open problems, gaps, and shortcomings that limit the uptake and use of XR by disabled students in online and distance learning contexts.

Online and distance learning offers flexibility by providing comprehensive support and study materials that can be worked through asynchronously, alongside employment or other responsibilities. The flexibility of asynchronous learning, however, is of little benefit if the technology used to mediate learning is inaccessible to some of the students. Therefore, to ensure XR benefits distance learning students, clarity is needed on the educational affordances of XR and how it can be used by students to develop and demonstrate the required learning outcomes.

Accessibility comes with a range of related notions. In terms of cost, it is defined as having a similar required effort to access for someone with a disability, compared to without [1]. In terms of opportunity, it can also be seen as the number of opportunities available, not just the ones taken (ditto). It can be defined regarding its outcome, i.e., digital inclusion. There is tension between accessibility and the digital literacy needed to turn opportunity into action, i.e., the users' knowledge, skills, or other abilities for operating digital environments. Barber et al. [2] identify digital access as a key prerequisite for education, to avoid what they term 'digital poverty'. They suggest that for successful implementation, appropriate devices, software, robust technical infrastructure, reliable internet access, trained instructors, and appropriate study places are essential.

As we will show, despite the legal context being enshrined quite widely into law (e.g., in the UK), only a few guidelines exist and there is a general lack of (but appetite for!) reliable standards. Moreover, existing work dates rapidly and leaves open wide gaps. The recent rise of AR smart glasses, for example, also as assistive technology (e.g., to enhance vision or for live captioning), warrants further investigation in the context of learning. While the status quo in accessible XR learning generally seems to be advancing, there are open gaps and underused opportunities that can be identified in the literature. [26] highlights the role multiuser AR/VR could play in overcoming social isolation for disabled people, as well as providing improved access to physical space by linking with digital elements. [27] reviews existing AR research on disability type against interaction tasks and techniques, postulating that more effort is needed to involve disabled people in system design to overcome restrictions of existing prototypes. [28] provides a research and development agenda, expressed along recommendations for hardware and for software, when using XR for users with physical, visual, hearing, or cognitive disabilities. It emphasizes the importance of open APIs and the role of open source as catalysts, and highlights, amongst other points, future innovation potential regarding haptics. [33] proposes a developing XR accessibility framework with the aim of providing developers with an approach to embedding diverse accessibility features into their XR applications, particularly for users who are blind or have visual disabilities.

The rest of this paper is organized as follows. First, we define XR in distance learning and the associated accessibility needs that are faced by educational (distance learning) institutions. Then, we review existing standards and regulations, new endeavours, and key organizations involved in the regulatory context. Drawing on the presentations and discussions at a workshop on XR and accessibility, held for staff at the authors' institution in November 2023, we highlight good practices and key themes. Next, we translate the standards and legislation into our education-specific context to enable accessible distance learning using XR. A discussion of gaps and open problems rounds up the review, and the paper concludes with a summary and next steps.

2 XR and Accessibility in Online and Distance Learning

Distance learning is a form of education where students and teachers are not colocated. The Open University (OU) is a distance learning university and an open entry institution. These features enable the OU to operate at scale, with students spread throughout the UK and beyond, and to support a wide range of students to participate in higher education. Course materials are developed in multidisciplinary module teams that include academics, educational technologists, and media specialists. OU students receive academic support on each module from their Associate Lecturer, and course choice, careers advice, and studying support from specific teams within Student Support Services. The OU currently has over 200,000 students, 70% of whom are in employment during their studies [3].

The latest figures published by the Higher Education Statistics Agency report the student numbers for the 2021/22 academic year from 285 higher education providers in the UK [4]. In these, a total of 451,580 out of 2,862,620 (16%) students studying in the UK declared having a disability. The OU is the largest provider of higher education for disabled people, with 37,118 students declaring a disability. As a proportion of the total number of students, this equates to 25% (37,118/151,840). Therefore, the accessibility requirements of disabled students using XR need to be addressed in order for XR to be applicable for higher education in general and for online and distance learning in particular.

The number of student declarations across the HESA categories of disabilities (listed in Table 1) help to illustrate the prevalence of each category. Of these, 61% are by students with a specific learning difficulty (such as dyslexia or attention deficit hyperactivity disorder) or a mental health condition. Although XR may be considered as a primarily visual medium, to use XR effectively in higher education, it is important to consider the specific accessibility requirements of disabled students. Moreover, the affordances XR provides for immersive learning experiences to students in each disability category need to be taken into account.

Staff at the university have realized that achieving accessibility for students requires a whole-university approach, alongside responsibility taken in each area. In this regard, pan-university groups and networks aim to achieve consistency and improvement across teaching and systems, while champions and coordinators provide a point of contact and specific understanding in their faculties and units [6]. When there are innovations in teaching and learning, faculty accessibility coordinators can identify activity and subject-specific barriers to accessing and engaging with learning. The digital accessibility of platforms and procured tools can be assessed for wider use across the university.

Table 1. The number of student declarations in 2021/22 for the categories of disabilities reported by the Higher Education Statistics Agency (taken from [5]) and the percentage of declarations.

HESA disability category	Number of student declarations in 2021/22	Percentage of declarations
A specific learning difficulty	134,320	32.3%
Blind or a serious visual impairment	3,700	0.9%
Deaf or a serious hearing impairment	6,980	1.7%
A physical impairment or mobility issues	8,900	2.1%
Mental health condition	119,480	28.7%
Social communication/Autistic spectrum disorder	18,820	4.5%
A long-standing illness or health condition	36,235	8.7%
Two or more conditions	56,875	13.7%
Another disability, impairment, or medical condition	30,645	7.4%
Total number of students declaring a disability	415,955	100%

3 Standards and Regulation

Clearly defined standards regarding XR accessibility are needed to avoid misunderstandings and surprises, both for students and for educational providers. Such standards can be established in multiple ways, for example, by good common practice, by voluntary alignment, or by regulation. Dedicated standards-developing organizations exist, some of them working at an international level, whose mission is to build consensus. Standards on XR accessibility are about XR technology and its societal ramifications, thus falling into the remit of a number of standardization bodies. These include, but are not limited to: the World Wide Web Consortium (W3C), the International Standards Organization (ISO, and its connected national membership organizations), CEN and Cenelec in Europe, and the Standards Association of the Institute of Electrical and Electronics Engineers (IEEE-SA). Each of these organizations has embarked on endeavours contributing to the standardization required to facilitate improved XR accessibility. However, none of the proposed initiatives and projects have provided sufficiently advanced guidance to cover the requirements of accessibility in XR.

Protection against discrimination is a natural right, written into human rights charters worldwide (UN UDHR, 1948; EU CFR, 2000) and widely adopted as law (Treaty of Lisbon, 2009). In the UK, the Equality Act (2010) is the broad protectorate against discrimination on the grounds of disability (for Northern Ireland, see the Disability Discrimination Act 1995). For Higher Education, this means anticipating the requirements of disabled students to ensure equality of access. Acting alongside this primary legislation, but sitting at a more granular level, the particular accessibility regulations, PSBAR [6], specify a minimum legal benchmark of ensuring that the websites, mobile apps, and digital content of public sector bodies comply with the Web Content Accessibility Guidelines (WCAG) 2.2, conforming to Level AA [7]. Implementation and monitoring of the PSBAR is the responsibility of the Government Digital Service (GDS).

The WCAG, a set of technical standards, was produced and is maintained by the World Wide Web Consortium (W3C), the leading standards body for the web, by an international, multi-stakeholder community of expertise. At the moment, the WCAG does not make specific reference to XR and covers digital accessibility more broadly. Within the W3C, further work is ongoing, originating in the wider working groups around content accessibility for the Web, yielding the XR Accessibility User Requirements, XAUR [8].

XAUR identifies key accessibility challenges as well as common user requirements for AR/VR use cases. Among the listed key challenges are "overemphasis on motion controls" and, connected, the requirements on particular physical positions for use (e.g., standing or sitting). A lack of spatial audio, vendor lock to OEM hardware and lack of support for assistive hardware, and a lack of exploration capabilities are also mentioned. Furthermore, XAUR discussed the importance of multi-modality in inputs and outputs, postulating that each input modality should be able to stand on its own, to support people with specific disabilities (speech, keyboard, switch, gesture, eye-tracking). The document continues to list a range of user requirements regarding customization of input controls and output presentation, additional support for sensory substitution (captioning, sign language), navigational supports, temporal controls and motion configuration support.

CEN, the European Committee for Standardization, published a workshop agreement on 'XR for learning and performance augmentation', a 'standards of standards' type of recommendation. It provides an overview and pointers to several existing standards required for the successful implementation of XR in education and training. This includes a review of IEEE P1589-2020, the standard for Augmented Reality Learning Experience Models, but also holds a dedicated section 6.1 on XR accessibility. Within that section, adopters are urged to commit to user-centered design and conformance to anti-discrimination legislation. Moreover, they make a proposal for a level model where the appropriate response to identified accessibility issues can be mapped to the adequate response level of hardware, operating system, application library, application, or embedded media [9].

Within the International Standards Organization, there are a wide variety of upcoming projects and standards available relating to XR, though none directly regarding XR accessibility (yet).

Within the IEEE standards association, there is ongoing work around XR ethics, which also links to accessibility. Most notably, this includes a report of the Global Initiative for XR ethics [10], focused on ethics, diversity, inclusion – and accessibility. Fox and Thornton [11] raise several concerns, including regarding predatory inclusion, increasing bias, and privacy, while acknowledging potential for remote work, more inclusive representation, in selected areas even medical treatment, combating isolation, and raising awareness and empathy with disabled people.

In the review of the XR Association's developer guidelines [13], they highlight in particular configurability and control, also with regard to sensory overload. Moreover, quicker ways for recovery from error, possibilities to configure speed, time for decision-making, and set up of time-saving automation are mentioned. They also list as important bypass functions, visual configurability (font and object sizes, colour schemes, captioning/read aloud, contrasts, signing), directing user focus in 3D space, and facilitating help.

There are also industry guidelines, like Apple's Human Interface Guidelines (2023) [12], which postulates a commitment to simplicity, perceivability, and personalisability as overarching design principles, paired with the recommendation to audit and test for accessibility. For a comparison between XAUR, Apple's human interface guidelines, and the more generic usability guidelines, see [14].

4 Examples of Good Practice

Within this section, we identify current and upcoming examples of accessible XR learning, to highlight good practices established so far in our institution. We identify mature activities in the XR space to date across teaching and research as a means to seed discussion and see where and how accessibility was considered. These are three carefully selected examples.

The first is about research and development of an augmented 2D haptic drawing system for people with low or no vision [15]. The second is about the development of a virtual reality courtroom and associated activities for teaching Law to students who may have little or no access to a physical courtroom space. The third highlights the use of 360° virtual field trips, which had been piloted and evaluated in Environment, Earth, and Ecosystem Sciences teaching.

Fig. 1. 360 panorama virtual field-trip in Environmental Science (left), virtual courtroom (middle), and haptic drawing support (right).

While the first explores the use of assistive devices to support design work for people with visual impairment, the second looked at an immersive scenario. The third focuses on an accessible rich internet application with improved keyboard access (tab order, arrow key navigation, zoom) and captioning / text alternatives (alt tags on all hotspots, image descriptions, closed captions / transcripts). Issues raised by students here were to do with the lack of navigational feedback (e.g. read out the angles as you turn or direction you face) and bandwidth requirements.

As part of our openXR studios movement, we have also identified three key enabling technologies currently being explored by the OU, that are expected to have greater impact in the future, including implications for accessibility. These include Motion Capture technologies, which are regarded as particularly valuable in Sports and Fitness-related teaching. Additionally, the possibilities of Volumetric Video offer a new level of presence and realism in augmented and virtual reality spaces. Moreover, there is the strong potential of Virtual Production technologies for distance education.

5 Translating Obligation into Operation

There are two types of reasonable adjustment: anticipatory (during planning and production of teaching materials) and responsive (which involves responding to student requests during their learning). There is increasing focus on anticipatory adjustments, which means requiring teaching materials to contain embedded accessibility, reserving responsive adjustments for situations that have not been anticipated.

To achieve either of the above, guidance needs to be in place for those developing the technology, software, and content. In the case of XR, as noted in earlier sections, attempts to produce standardized guidance similar to the WCAG have been made by various organizations. So far, nothing has been created with the same coverage or availability for general adoption, see Section 3. Due to this lack of existing guidance, the task of implementing accessibility for XR technologies is focussed in the main on translating what the WCAG does cover to XR software and hardware. This is most often accomplished by combining those relevant guidelines from the WCAG with current best practice, and information gleaned from other relevant sources – such as the W3C's XR User Requirements document [9], the Making Content Usable for People with Cognitive and Learning Disabilities (COGA) document [16], the WebXR Standards and Accessibility Architecture Issues document [17], and the Authoring Tool Accessibility Guidelines (ATAG) [18].

These sources independently lay out some of the current accessibility-related user needs, and possible solutions, and they give advice for making digital content accessible to cognitively and neurologically disabled users, but do not provide guidance in the same way that the WCAG does. Even though they give XR developers a good starting point to work from, a holistic, and standardized singular set of guidelines would be beneficial.

Educational practitioners want to develop innovative teaching, and are often excited by the possibilities of XR for learning, but they are also required to provide accessible teaching. They need to be sure that teaching materials and technologies will be accessible and not leave them open to claims of unfairness or discrimination from students. Any lags in guidance and understanding of accessible XR are likely to lead to confusion and a further lag in developing innovative XR teaching.

Educational practitioners generally have a requirement for stable solutions, and are often less comfortable with the rapid development and try/fail processes common in technology development. The costs, in time as well as money, of redeveloping teaching materials when technologies develop or move on are beyond the means of many educators. They are unlikely to be comfortable with a situation of perpetual beta. There will be exceptions to this, especially in areas of technology learning where there is a requirement to keep up to date, and where the learning aims are for students to be able to deal with a rapidly developing technology landscape, but in the main, there is a need for stability. Notably, distance learning models are often geared to large student numbers and a long course lifetime. For example, at the Open University a module will have a projected initial life of 4 years, with a rewrite and redevelopment then extending that life for a further 4 years.

As there are no firm guidelines yet in place, a lot of the work in this area will rely on inspection and testing – including automated tools, skilled testers, and end users – to pin down and rectify as many accessibility issues as possible before going live. Part of this will necessarily also include attempting to anticipate problems users may have, drawing on existing guidance and experience in general digital software and technology, as well as previous and current iterations of XR.

Those who work in the accessibility profession utilize multiple methods to discover issues, including 'AI' augmented automated tools such as WAVE, axe DevTools and SiteImprove – all of which we currently use at the Open University. These tools check the software, application, or website against a set list of criteria from the WCAG and produce a summarized report. While these tools are invaluable, they are prone to identifying false or non-existent issues, and they are limited by their ability to only check against a specific list of criteria. They can not check for anything that requires a human understanding, such as logical content flow, logical tab orders and keyboard access, meaningful text alternatives, visual impact, etc.

As such, there will always be a need for evaluation by both testers who know the criteria and users with lived experience, especially as none of the existing automated tools are geared toward testing XR experiences. Including users and testers with lived experience of disability at all levels should be considered a requirement. Developers and even experienced testers may make assumptions and draw conclusions that they think are what different disabled communities require or want, but miss the mark by a wide margin.

Currently, the Open University resources a small, specialized team of accessibility and usability testers, the Accessibility and Usability Evaluation team (AUE). Team members, some of whom have lived experience of a range of disabilities, have a broad background in disability, education, and development. In addition, the team administers a student panel, which allows for user testing and research projects focused on user-centred design with current students. There is a high proportion of students who have declared a disability participating in panel activities. The team conducts evaluations of digital content and developments against the WCAG while incorporating best practice. It also provides guidance and acts as a centre of expertise in digital accessibility for staff. Alongside other advisory groups, such as Securing Greater Accessibility (SeGA) the AUE team has begun research into XR accessibility with the aim of producing guidance for those module production teams incorporating XR into their teaching and learning materials.

The problem then is that the lag between XR technology development and use in teaching is likely to grow. This is especially true in resource-poor settings and where there are requirements for security and stability, unless XR-specific accessibility guidance is produced and widely adopted. The team currently relies on the interpretation of existing generalized digital guidance, and expert and user testing to ensure accessibility, but this is not sustainable in the long term.

6 Discussion: Gaps and Open Problems

In this discussion, we highlight key issues concerning academics, educators, developers, and accessibility experts regarding the use of XR in teaching and learning, particularly in online and distance settings. Rather than looking to create a comprehensive list, the aim is to explore some gaps and barriers, raise questions, and indicate areas where further research and consensus building across different communities operating in this space would be valuable. Figure 2 shows the topic themes which are explored below.

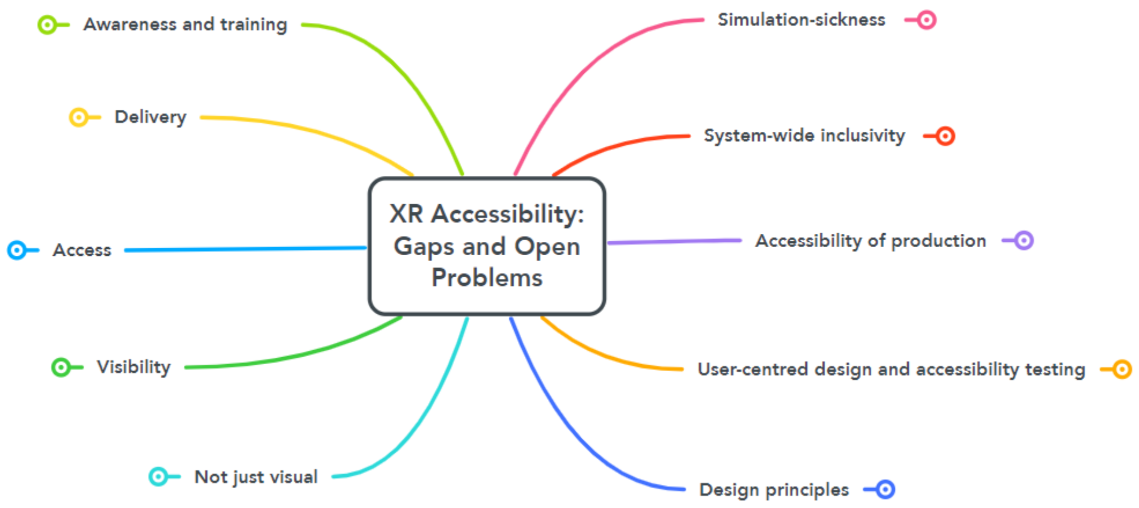

Fig. 2: Gaps and open problems for XR in teaching and learning, particularly in online and distance settings.

Simulation-sickness: An often-raised issue is the experience of nausea, or simulation-sickness, and other forms of discomfort when people use VR. Questions include: what are the frequencies and levels of discomfort, to what extent are there individual differences, and what potential is there to manage or avoid it? Studies show that many users experience no, or only minor, discomfort with contemporary VR systems, and there are indications that AR and MR (including both the real and physical world) is less likely to cause simulation sickness than complete VR [22]. However, the concerns, misconceptions, and connected worries about this pose a real barrier to uptake. There is an opportunity here to provide a comprehensive review regarding recent technological advancements to address and alleviate these concerns, and research is ongoing regarding how smart use of technology can help mitigate and manage symptoms where and for whom they appear.

System-wide inclusivity: representation and inclusion of people with different accessibility needs is important for exploring problems and enhancing accessibility. Making sure this occurs throughout the system will highlight issues that occur at different stages in XR development and use.

Accessibility of production: if authoring tools (i.e. the software and services that developers and designers use to develop and produce XR content) such as those used for motion capture, volumetric VR and virtual production, and their assembly into XR applications are not accessible, this will affect the diversity of production teams. The WCAG has an initiative on ‘authoring tools accessibility guidelines’ (ATAG). The aims of it are, firstly, to make the authoring tools themselves accessible, so that disabled people can create web content, and, secondly, to help authors create more accessible web content [18].

User-centred design and accessibility testing: early involvement of disabled people in pilots and evaluations of immersive learning, including participatory discussions, can inform design at early stages so that their inputs can have real impact. This is also with a view on empowerment [32].

Design principles: Starting with design principles to always support multiple interaction forms and multiple representations can help with personalization and adaptation (e.g., as proposed in Universal Design for Learning [23]). It is critical to understand how assistive technologies work and are used by disabled people, and what alternative means there are for accessing XR. Navigation and interaction in virtual spaces can be facilitated by adding alternatives and removing barriers. Customization of displays and interactions, e.g. allowing users to enlarge text or visuals or move between devices, and ensuring interoperability is important so that assistive technologies and alternative means of access can function. There may be different challenges and expectations for accessibility in live experiences compared to produced experiences.

Not just visual: There is a reliance on visual perception in many immersive experiences. However, some XR experiences focus specifically on other senses to overcome disability-related barriers; for example, the review [19] of the use of audio in VR highlights accessible or assistive technologies, including the use of ‘audio-only’ VR for people with visual impairments. [20] found there was great potential for using XR for blind and low vision, however users often wanted multimodal feedback. Here, it was deemed indispensable to involve low-vision users at every stage of the decision-making and development process. XR has the potential to be adaptive and allow engagement through particular channels and senses.

Visibility: Diversity in representation of different people in the learning resources and virtual spaces is critical, e.g., representing wheelchair users and other disabled people as avatars. As well as making sure disabled people can see themselves represented in these environments, and non-disabled people can see diverse representations, this can highlight the need to consider accessibility issues of physical, augmented and virtual environments.

Access: There are also accessibility issues around digital inclusion and poverty; educators and developers recognize there are barriers raised by requirements for high connection speeds or large downloads, and that there are also trade-offs with producing lower fidelity experiences, e.g., in levels of immersion.

Delivery: Some educators are able to provide XR access for students at their school or university. The online and distance learning context, however, prevents access to specialist equipment that is too expensive to roll out at scale for students, for example, VR headsets and haptic devices. What types of solutions and models could be used to provide access to XR for distance learners? Distance learners will be engaging in immersive learning activities in their home environments, or in public spaces. What are the requirements for, and impacts of using XR in these places and spaces for students?

Awareness and training: Awareness of web accessibility and inclusive learning is still limited, and XR adds new requirements that are still developing. What should be done to enhance training and awareness for educators and developers on making XR accessible and inclusive? Sharing findings from pilots is incredibly useful, but also there is a need to understand how these can scale up into wider practices and feed into guidelines for how XR should be used.

7 Summary and Next Steps

In this paper, we provide a comprehensive overview of educational affordances of XR technology in the context of open and distance learning, and the associated accessibility needs educational institutions face. We provide insights into legal frameworks, standards, and real-world applications related to XR accessibility in education, highlighting key themes and connected good practice. We elaborate a perspective on how to translate standards and legislation into an educational context to facilitate accessible distance learning using XR. Furthermore, we identify gaps and open problems in the implementation of XR technology for accessible online and distance learning.

The gaps and open problems we identify indicate valuable areas for further research and consensus building. For example, concerns over simulation-sickness and other discomforts experienced by VR users pose a barrier to its widespread use in education, and a comprehensive review of recent advancements that address and alleviate these concerns would be of great value to the community.

Inclusivity of, and for, people with different accessibility needs is critical for exploring problems and enhancing accessibility. This inclusivity needs to be system-wide to have a real impact; this ranges from accessibility of production tools and diverse teams, through early and participatory user-centred design (which will also capture identity and value related design considerations) and accessibility testing, to the creation of design principles that support multiple interactions and multiple representations. Diversity of representation is required within virtual spaces as well as within development and production teams and processes.

Visual perception, key to many immersive experiences, is not available to all, so consideration of other senses is needed to overcome disability-related barriers. Investigation is required into additional accessibility issues around digital inclusion and poverty and the need for specialist XR equipment that is too expensive to roll out at scale for students, especially those studying online and at a distance. As XR technology develops, so do the accessibility considerations, which in turn require additional awareness and training.

Quality education for everyone is one of the primary sustainable development goals declared by the United Nations. It is a special area where obligations arise for all actors involved to ensure equitability and prevent exclusion. Even more so, “as Higher Education continues to broaden out”, as [21] put it, who find, in their survey of 3,030 students in eight geographic regions of the world, “17% reported some kind of disability”, much in line with numbers reported to HESA, see Section 2. This is also to set a lighthouse example of how to achieve accessibility for other sectors to follow.

Educators and their institutions have a responsibility to ensure all their teaching materials are accessible to students. The same has not always followed in the wider world of XR developments, leaving educators unsure whether third-party systems are appropriate for use. Ensuring or encouraging third-party suppliers to make their systems and content accessible would be useful in bridging this gap. Standards that are built in dialogue and, ideally, consensus would help provide clarity over what needs to be supported, in turn influencing procurement processes. This will also help overcome existing validation gaps. The majority of evaluations screened in [29] are from western-world, white, university-educated participants in the age bracket of 20–50 years old, with a large part of the studies reviewed gender-biased one way or the other. If left unresolved, these gaps may lure Higher Education governance into the assumption that XR learning technology is accessible today: a car crash, in analogy to the example presented in [30], result of not preparing the self-driving car-AI of the future for anticipating a wheel-chair rolling backwards onto an intersection.

A look at the bigger picture shows that regulation is developing, and practice is emerging. Greater involvement of and connection between a range of communities from developers and regulators to educators and accessibility experts through to students, however, will be crucial in progressing the accessibility and uptake of XR in teaching and learning. This applies to delivery as well as production of XR learning content. We have already begun evaluating our own XR authoring tools to help improve accessibility support for, e.g., Augmented Reality learning experience design [24], but further tools are needed, especially for supporting testing. Efficiency gains can be expected from improvements of testing methods, better automation tools, with clearly explained limits, as they are different from existing methods, tools, and their limitations.

New research questions arise, e.g., regarding the aim of XR accessibility: is this to assist an individual or to increase efficiency of work [25]? Transferability between contexts requires further investigation [25], so it becomes possible to predict whether success in one case can be adopted to others. Nevertheless, there are many unmet challenges and identified gaps that warrant future research, if we want to turn emerging opportunities into realities. This includes recognising the need to resource and research investigating more broadly the perspectives of a diverse range of stakeholders of accessible XR open and distance learning. This means on the one side relevant industries (e.g., gaming, media), but also educators and developers. On the other side, this means looking at specific disability communities (e.g. blindness, hearing loss, or autism). This requires investigating comprehensively their needs, aims, and motivations, and working out especially how these are affected or even hindered by policy or resourcing. New opportunities for production of learning contents in open and distance learning are arising, like volumetric video and motion capture. Further research is needed, how these production technologies are translated into accessible learning designs and how identity and values of disabled students and staff are reflected into approach, testing, methodology, and delivery of accessible XR learning. Opportunities are visible for automated XR accessibility testing and for novel production support tools (e.g., AI-enabled sign language support) to better meet resource constraints and lower entrance barriers.

The technologies on the XR spectrum offer potential to overcome physical limitations in unprecedented ways – using sensory substitution to map what is available in one modality on one scale to other modalities and scales. Interaction devices and delivery systems for other senses than the audiovisual one may well be less advanced, at least regarding technology available in the public realm. The trajectory of how these technologies might develop, however, promises inclusiveness innovation in the very near future, both in learning and regarding its general use as assistive technology. The European Space Agency has selected John McFall as its first ‘parastronaut’, conducting a feasibility study of how human space flight needs to be adapted to accommodate the needs of disabled people [31]. If we are able to solve accessibility for human space flight, one would think that we can also master the diverse challenges of accessible XR learning.

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References

1. Cascetta, E., Carteni, A., Montanino, M.: A new measure of accessibility based on perceived opportunities. Procedia - Social and Behavioural Sciences 87, 117–132 (2013). doi: 10.1016/j.sbspro.2013.10.598.
2. Barber, M.: Gravity assist – propelling higher education towards a brighter future (2021). Available: https://www.officeforstudents.org.uk/publications/gravity-assist-propelling-higher-education-towards-a-brighter-future/. Last accessed 2024/02/25.
3. The Open University: Facts and figures - About The Open University. Available: https://about.open.ac.uk/strategy-and-policies/facts-and-figures. Last accessed 2024/02/27.
4. HESA: Higher Education Student Statistics: UK, 2021/22 - Student numbers and characteristics. Available: https://www.hesa.ac.uk/news/19-01-2023/sb265-higher-education-student-statistics/numbers. Last accessed 2024/02/27.
5. HESA: Table 15 – UK domiciled student enrolments by disability and sex 2014/15 to 2021/22. Available: https://www.hesa.ac.uk/data-and-analysis/students/table-15. Last accessed 2024/02/27.

6. Pearson, V., Lister, K., Coughlan, T.: Accessibility Coordinators: A model for embedded, sustainable change towards inclusive higher education. In: Proceedings of the 12th Annual International Conference of Education, Research and Innovation (ICERI 2019), pp. 3127–3136 (2019). doi: 10.21125/iceri.2019.0798.
7. The Public Sectors Bodies (Websites and Mobile Applications) Accessibility Regulations 2018. Available: https://www.legislation.gov.uk/uksi/2018/852/contents/made. Last accessed 2024/02/21.
8. W3C: Web Content Accessibility Guidelines (WCAG) 2.2 (2023). Available: https://www.w3.org/TR/WCAG22/. Last accessed 2024/02/21.
9. W3C: XR Accessibility User Requirements (2021). Available: https://www.w3.org/TR/xaur/. Last accessed 2024/02/21.
10. European Committee for Standardization: eXtended Reality for learning and performance augmentation – methodology, techniques, and data formats. CEN workshop agreement (2023). Available: https://www.cencenelec.eu/media/CEN-CENELEC/CWAs/RI/cwa18006_2023.pdf. Last accessed 2024/02/27.
11. Fox, D., Thornton, I.G.: White Paper – The IEEE global initiative on ethics of eXtended Reality (XR) Report – eXtended Reality (XR) ethics and diversity, inclusion, and accessibility, 1–25 (2022). Available: https://ieeexplore.ieee.org/document/9727122. Last accessed 2024/02/27.
12. Apple: Human Interface Guidelines. Available: https://developer.apple.com/design/human-interface-guidelines/. Last accessed 2024/02/24.
13. XR Association: Developers Guide: An Industry-wide collaboration for better XR, Chapter 3: Accessibility & Inclusive Design in Immersive Experiences. Available: https://xra.org/research/xra-developers-guide-accessibility-and-inclusive-design/. Last accessed 2024/02/27.
14. Koch, S., Ableitner, T., Zimmermann, G.: Comparison of guidelines for the accessible design of augmented reality applications. Computers Helping People with Special Needs, 89–98 (2022). doi: 10.1007/978-3-031-08645-8_11.
15. Bowers, L., Hayle, R.: Creative haptics: An evaluation of a haptic tool for non-sighted and visually impaired design students, studying at a distance. British Journal of Visual Impairment 39(3), 214–230 (2021). doi: 10.1177/0264619620912771. Last accessed 2024/02/27.
16. W3C: Making content usable for people with cognitive and learning disabilities. W3C Working Group note 20 April 2021 (2021). Available: https://www.w3.org/TR/coga-usable/. Last accessed 2024/02/24.
17. W3C: Understanding WebXR and accessibility architecture issues (2021). Available: https://www.w3.org/WAI/APA/wiki/WebXR_Standards_and_Accessibility_Architecture_Issues. Last accessed 2024/02/24.
18. W3C: Authoring Tool Accessibility Guidelines (ATAG). Available: https://www.w3.org/WAI/standards-guidelines/atag/. Last accessed 2024/02/24.
19. Bosman, I. de V., et al.: The effect of audio on the experience in virtual reality: a scoping review. Behaviour & Information Technology 43(1), 165–199 (2024). Available: https://doi.org/10.1080/0144929X.2022.2158371. Last accessed 2024/02/27.
20. Kasowski, J., Johnson, B.A., Neydavood, R., Akkaraju, A., Beyeler, M.: A systematic review of extended reality (XR) for understanding and augmenting vision loss. J Vis 23(5), 5 (2023). doi: 10.1167/jov.23.5.5.
21. EY: Is your university's transformation centered on tech or people? Report. Ernst & Young Global Limited.
22. Vovk, A., Wild, F., Guest, W., Kuula, T.: Simulator Sickness in Augmented Reality Training Using the Microsoft HoloLens. In: Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, 1–9 (2018). doi: 10.1145/3173574.3173783.
23. Rose, D., Meyer, A.: Universal Design for Learning. Journal of Special Education Technology 15(1), 67–70 (1999).
24. Shidende, D., Kessel, T., Moebs, S.: Towards accessible augmented reality learning authority tool: a case of MirageXR. In: 2023 IST-Africa Conference, 1–13 (2023). doi: 10.23919/IST-Africa60249.2023.10187746.
25. Blattgerste, J., Renner, P., Pfeiffer, T.: Augmented reality action assistance and learning for cognitively impaired people: a systematic literature review. In: Proceedings of the 12th ACM International Conference on Pervasive Technologies Related to Assistive Environments (PETRA '19), 270–279 (2019). doi: 10.1145/3316782.3316789.
26. Dick, E.: Current and Potential Uses of AR/VR for Equity and Inclusion, ITIF. Available: https://itif.org/publications/2021/06/01/current-and-potential-uses-arvr-equity-and-inclusion/. Last accessed 2024/02/27.
27. Žilak, M., Car, Ž., Čuljak, I.: A systematic literature review of handheld augmented reality solutions for people with disabilities. Sensors 22, 7719 (2022). doi: 10.3390/s22207719.
28. Creed, C., Al-Kalbani, M., Theil, A., Sarcar, S., Williams, I.: Inclusive augmented and virtual reality: a research agenda. International Journal of Human-Computer Interaction, 1–20 (2023). doi: 10.1080/10447318.2023.2247614.
29. Auld, B.: UX & UI Design. Available: https://vimeo.com/825060302/5dfb07656c. Last accessed 2024/02/27.
30. Treviranus, J.: We count: fair treatment, disability and machine learning. In: W3C workshop on web and machine learning (2020). Available: https://www.w3.org/2020/06/machine-learning-workshop/talks/we_count_fair_treatment_disability_and_machine_learning.html. Last accessed 2024/02/27.
31. ESA: John McFall. Available: https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Astronauts/John_McFall. Last accessed 2024/02/27.
32. Seale, J., Garcia-Carrizosa, H., Rix, J., Sheehy, K., Hayhoe, S.: A proposal for a unified framework for the design of technologies for people with learning difficulties. Technology and Disability 30(1-2), 25–40 (2018). doi: 10.3233/TAD-180193.

33. Valakou, A., Margetis, G., Ntoa, S., Stephanidis, C.: A Framework for Accessibility in XR Environments. In: Stephanidis, C., Antona, M., Ntoa, S., Salvendy, G. (eds) HCI International 2023 – Late Breaking Posters. HCII 2023. Communications in Computer and Information Science, vol 1958. Springer, Cham. doi: 10.1007/978-3-031-49215-0_31.