Towards eXtended Universal Design

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Abstract. Even though eXtended Reality (XR) technology has been trialed in various projects in primary and secondary education, its lack of universal design hinders further adoption. In this paper, we present the results from focus group interviews with representatives from Norway's private and public sectors, in which we investigated their practical experiences and opinions about the accessibility and usability of XR technology in schools. We summarize practical opportunities and challenges related to the need for universal design of XR technology, both in general terms and in education specifically. Moreover, we compare the results to a previously conducted selective and weighted literature review. Five major future research needs to improve the universal design of XR technology emerge: The need to (1) increase co-creation, (2) identify and understand barriers, (3) develop solutions for said barriers, (4) advance standardization, and (5) develop evaluation methods and tools.

Keywords. eXtended Reality (XR); Primary and Secondary Education; Universal Design; Accessibility; Usability; Digital Learning; Information and Communications Technology (ICT).

1. Introduction

Extended Reality (XR) – an umbrella term for Virtual Reality (VR), Mixed Reality (MR), and Augmented Reality (AR) – has shown promising positive results for primary and secondary education, at the same time as decreasing hardware costs and increasing availability are expected to make XR even more ubiquitous in the future [1, 12, 14].

However, significant barriers in accessibility and usability for people with disabilities and varying abilities and a lack of universal design of XR technology exclude large groups of students and users in general [10, 14]. Especially, the practical implications of missing universal design for students with disabilities have been underrepresented in the literature [14]. Moreover, the lack of standards and evaluation methods has been pointed out as hindering the advanced universal design of XR technology [14].

In this paper, we investigate barriers that students with disabilities and varying abilities can encounter when using XR technology in education. We collected data from the literature and focus group interviews with stakeholders from Norway's private and public sectors. We identify opportunities, and challenges. Moreover, we discuss future research needs to advance the universal design of XR technology in education for all.

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2. Methodology

We organized three focus group interviews with 12 representatives from the private and public sectors: (1) representatives from user organizations for people with sensory (e.g., hearing and seeing), physical, and cognitive (e.g., dyslexia) disabilities, (2) educators from public primary and secondary schools, (3) decision-makers from municipalities, and (4) companies that develop XR applications for education in Norway. The goal of these interviews was to investigate the representatives' experiences with and opinions about ongoing, previous, and planned XR projects in Norwegian schools. Each focus group consisted of 2 to 5 participants. We asked the participants to share observed advantages, disadvantages, universal design, barriers, and solutions to said barriers, as well as the participants' opinions about future research needs of XR technology. Then, we summarized the opportunities that XR technology can offer for students with disabilities in primary and secondary education, as well as experienced barriers for people with different degrees of sensory, physical, and cognitive abilities (cf. 3. Results). We compared our findings with the results of a selective and weighted literature review that we conducted during the preparation of the focus group interviews [14] and defined future research needs to make XR technology more universally designed (cf. 4. Discussion).

3. Results

3.1. Opportunities

There are numerous opportunities for use of XR technology in primary and secondary education. General pedagogical opportunities have been reviewed elsewhere [13]: XR is first and foremost technology for mediating experiential learning. XR can bring abstract topics into a more practical learning context. XR can stimulate social interaction and collaboration and can help improve digital skills in students. XR can both challenge standard learning and invite alternative learning processes, both in students and educators. XR technology is likely to be increasingly present in future classrooms.
Moreover, XR can support weak students with learning disabilities or other challenges. XR is well-suited to support students who have difficulty concentrating or other cognitive challenges. One participant, for example, recounted their experience with adolescent boys who found it difficult to sit still and concentrate on the topic at hand. The participant explained that these teenage boys benefitted from being immersed in a digital environment, as digital interaction captured their attention and kept them busy in a different way than in the physical world. The children's visits to the virtual world are described as allowing them to be in their own bubble, being shielded from external distractions. Similar positive responses to XR technology have been observed by other participants working with children with various cognitive disabilities like Down syndrome, ADHD, autism, or social anxiety. One participant shared their experience of how XR technology motivated children with cognitive and physical disabilities to be more engaged and physically active. The participant recalled one project involving a child with Down syndrome that gained a different motivation for moving around while in a virtual world. They remembered the kid's mother saying: "I have seldom seen my kid so active and engaged as when in virtual reality!"

3.2. Challenges

XR technology can become yet another area for exclusion in education if its universal design is not addressed and its accessibility and usability are not increased sufficiently. XR technology lacks universal design, which often leads to the exclusion of students with disabilities, varying abilities, and other needs. Specifically, students with sensory (e.g., visual, and auditory), physical and cognitive disabilities or varying abilities encounter significant barriers preventing them from using XR technology for any length of time. Some of the participants voiced their concern about relying too much on XR technology in education when the technology lacks universal design. The barriers described below, likely exclude students with disabilities from using XR technology, either partially or completely. If schools decided to rely too much on XR technology for any given topic or subject, there would be an imminent risk of excluding students with disabilities and varying degrees of sensory abilities. Even students with common conditions like wearing eyeglasses could be excluded. One participant said: “We are afraid that the virtual world becomes just another area where people with disabilities are left out.”

Students with disabilities or common ability variations can encounter barriers connected to headsets and other physical barriers. Especially, head-mounted devices (HMD) for VR and MR are associated with significant barriers. HMDs can be challenging for students who need to wear eyeglasses, have a smaller head, or have a narrower interpupillary distance (IPD) than the average adult white male [3]. This makes the HMD uncomfortable to wear and use and is also a reason why many experience motion sickness. Other issues that give rise to discomfort that either reduce the time an individual can use MR/VR or they experience motion sickness are related to common vision problems such as no or poorer ability to perceive 3D visual content, differential sensitivity to depth, and/or motion cues [3,6,11]. As many as 5% of the population do not have the ability to perceive 3D, and 10–20% of the population have poor ability to perceive 3D in the physical, mixed, or virtual world [4,5]. Moreover, the physical setup of XR equipment can impose inconvenient, impractical, and even dangerous challenges for people with disabilities or different degrees of sensory ability. Managing cables for HMDs can interfere with assistive devices like headphones or wheelchairs. Setting up and interacting with XR devices can be particularly challenging for students with sensory, physical, or cognitive disabilities. One participant reported that one student in a wheelchair became so engaged and excited by the virtual world that they fell off their wheelchair.

Students with visual impairments face considerable barriers when using XR due to lack of multimodality, lack of accessibility of the (graphical) user interface, and potential incompatibility with assistive technology. Virtual worlds to date heavily focus on the visual experience, while often neglecting equivalent auditory immersion. One participant with low vision reported that they were missing a virtual sound landscape in which sounds have detail, create an atmosphere, and can be located. Moreover, there is a lack of auditory descriptions of visual objects and events. Users who have low vision or who are blind desire the option of enabling alternative modalities for visual events, scenes, or actions. This could, for example, be in the form of descriptive narration, or as alternative texts that are readable by a screen reader typically used by people with visual impairments. Likewise, (graphical) user interfaces are often inaccessible, especially when users rely on assistive devices like screen readers or magnifiers. Our focus group participants mentioned typical barriers like font sizes that were too small, contrasts that were not large enough or a busy and distracting background. One participant reported that it was sometimes not even obvious where to find the start button to initiate the game.

Students with physical and sensory impairments can encounter barriers related to incompatibility with assistive devices. Many XR devices and applications are incompatible with assistive technology like screen readers or hearing aids that are typically used by people that are hard of hearing. One participant mentioned that some devices could not be used in combination with headphones that would improve the auditory experience for people with hearing impairments. Especially, assistive technology connected through Bluetooth can raise significant complications because some XR equipment does not support additional external devices.

XR developers might repeat barriers that are well-known from other ICT areas, at the same time as they overlook simple solutions that could benefit multiple user groups simultaneously. Students with reading difficulties in the real world may also have difficulty reading text presented in the digital world. Barriers in the (graphical) user interface for people with visual disabilities, or missing subtitles are well known in other ICT areas like websites or movie clips. One participant who had experience working with dyslectic students emphasized that XR technology mirrored many of the barriers that they encountered from other ICT areas like websites, games, and digital media in general. For children with reading difficulties, texts are often too long, and the language is too complicated because designers and developers are trying to appear excessively sophisticated. Thus, our participants suggested reusing relevant guidelines from these ICT areas for XR technology. They mentioned, for example, the Web Accessibility Guidelines (WCAG) which offered best-practice examples for increased accessibility and usability of websites [16]. The participant emphasized that basic recommendations like "keep it simple!" – e.g., the use of simple understandable vocabulary or enabling the option of reading all dialog and text aloud – could increase accessibility and usability of XR technology significantly. Moreover, the participants pointed out that solutions targeted at one group often benefited other user groups as well. This is referred to as the curb-cut effect in universal design research [7]. Having text and dialog read-aloud, for example, will not only benefit students with visual disabilities but students with dyslexia as well. Likewise, blurring the background will not only increase readability for students with low vision but will also help the concentration of students with cognitive challenges.

More research on barriers for students with disabilities and varying abilities, and solutions to mitigate said barriers is needed. Most companies in our focus group interview expressed their commitment to helping students with disabilities and wished to produce universally designed XR technology. One company reported that they conducted a small study including people with cognitive disabilities financed by Norwegian authorities. At the same time, representatives from user organizations called for extended research on the practical barriers of XR technology for students with disabilities, as well as the implications of these barriers on education. Further research about universal design and its funding was desired by most participants of our focus group participants.

Narrow profit margins and high press from investors can discourage companies to focus more on the universal design of XR technology. Many XR content creators in Norway are small start-up companies with only a few developers and limited budgets and are often faced with tough financial decisions. Thus, they need to prioritize where and how to focus their efforts and resources. Some XR companies claim that they are advised by investors to prioritize content creation targeted at what they term the majority population of students (those without disabilities) first. They consider the group of students without disabilities to constitute the largest percentage of customers, and, therefore, the most profitable. When they do so, however, they also exclude those with common eye problems and those with visual impairments. Thus, they cater to just about half the population. In contrast, focusing on people with disabilities during development could lead to unexpected beneficial synergies. At the same time, companies need to weigh production costs against legal obligations that the lawmaker has put in place for digital learning aids as we will discuss in the next paragraph. The companies that we talked to confirmed that the universal design of their products was of high importance, but they lacked knowledge on how to achieve this.

As XR technology becomes more ubiquitous, legal requirements targeting the increased accessibility and usability of devices and applications, especially in education, become more likely. There are national and international laws requiring all digital teaching tools to be universally designed, like the Norwegian Anti-Discrimination Act or the Regulation on Universal Design of ICT Solutions covering among others websites and digital teaching aids [8, 9]. Even though the Norwegian law does not explicitly mention XR technology, representatives from user organizations argued that XR technology qualified as digital teaching aid sanctioned by the law when used as a teaching aid in the classroom. Moreover, the participants pointed out that it could be beneficial to invest in universal design early in the production process. One participant quoted experiences from the time when the ICT Regulation Solutions had first been enacted: Many companies and organizations had to remodel their websites to comply with WCAG as required in the regulation. This remodeling caused costs for the companies and organizations by additional time, effort, and resources that could have been avoided if they had incorporated compliance with the guidelines early in the design and development process. Some participants emphasized that making universal design an integral part of the design and development process could, thus, be more cost-effective in the long run.

There is a lack of guidelines, standards, and best-practice examples to support increased accessibility and usability during the design and development of XR devices and applications. Representatives from XR companies made clear that the general lack of practical guidelines and concrete best-practice examples was one of the main reasons why developers overlooked the universal design of XR devices and applications. As mentioned above, many XR software companies for the education sector are rather small and have limited resources. They claimed that they did not have enough leeway for experimentation because they must create content with a limited amount of people on a tight schedule. The companies we talked to complained that there was simply no time for investigations into which solutions worked best for students with disabilities or how viable solutions could be implemented. A standard of or even a set of clear guidelines and best-practice examples would mitigate the burden of finding effective solutions and their implementation. A standard would facilitate the integration of accessible and usable solutions by providing a clear roadmap or manual to manifest accessibility and usability for all into the agile design and development routines of XR devices and content creators.

4. Discussion

4.1. Comparison between the literature and the interviews

In our focus group interviews, we noted many common barriers for students with disability and varying abilities with what we found during a selective and weighted literature review [14]: For example, XR technology can offer opportunities for virtual access and inclusion, compensation for disabilities, safe spaces, personalization, assistive technologies, and rehabilitation [14]. In contrast, general challenges are mostly related to the lack of multimodality, practical issues when setting up or using devices, incompatibility with assistive technology, financial costs, health issues, overreliance on gamification, and ethical considerations [14]. Moreover, we reviewed common barriers for people with cognitive, sensory, and physical disabilities [14]. General opportunities in the classroom and systemic challenges of XR technology have been reviewed elsewhere [13].

Our focus group participants highlighted the general lack of universal design of XR technology for students with disabilities as one of the main inhibitors to implementing XR technology in education. This lack seemed to outweigh the few positive aspects that they reported for students with disabilities. In contrast, they mirrored many practical barriers related to inaccessible hardware as well as inaccessible navigation and interaction methods, and incompatibility with assistive technology. Similarly, content-related barriers like the lack of multi-modality and inaccessible (graphical) user interfaces have been reported by both the literature and our participants. Thus, our findings reflected and confirmed several of the barriers described in international literature and added some more practical examples for education. Moreover, our focus group participants underlined the importance of focusing future research on the universal design of XR technology. Representatives from user organizations for people with disabilities stressed that XR technology must become more accessible and usable before wider deployment in schools can be achieved. They especially pointed out the need to ensure that students with disabilities and varying degrees of ability were not excluded from this emerging technology. They gave an emphasis to education that was universally accessible by all students.

4.2. Need for future research

Even though our focus group interviews investigated XR technology in education, the discussed accessibility and usability challenges are rooted in a general lack of universal design of XR technology. Thus, we will discuss future research needs to improve accessibility and usability of XR technology on a more general level in the following discussion. More precisely, the universal design of XR technology needs to be improved by breaking down barriers for students and users in general with disabilities to make XR technology more accessible and usable for all. Future research should focus on co-creation and user involvement, barriers and their solutions, guidelines and best-practice examples, and evaluation of the degree of universal design and effects. This research should contribute toward the general standardization of the universal design of XR technology. Moreover, future research needs connected to pedagogical integration, digital skills, digital infrastructure, and funding are also necessary [13].

There is a need to strengthen co-creation involving XR software companies and device manufacturers, students and educators, and user organizations representing people with disabilities. User involvement during the design, development, and testing of XR technology is the key principle of inclusive design approaches (IDA) and proved to be necessary to increase the universal design of a product or service in general [2]. Relevant methods during such co-creation processes are user tests, focus groups, and surveys. Recruitment of students and users with disabilities can be done through user organizations, co-operations with special ed schools, or by addressing students directly through social media.

There is a need to identify the barriers that users with disabilities encounter when using XR devices and applications, both generally and in education specifically. Some studies have started with the identification of such barriers [15, 17]. However, there is a need for further investigation of barriers for different user groups in general and students with disabilities in specific. This investigation should also highlight the challenges of XR technology, specifically in the classroom. The focus should be on students with cognitive, sensory (e.g., visual, and auditory), and physical disabilities as these categories represent the most prominent disability groups among students and as XR technology is a predominantly visual medium. Moreover, there should be an assessment of the limitations of XR technology, including an evaluation of where and when XR as a tool for mediating learning in schools is beneficial.

We need to advance the development of solutions or strategies to mitigate the investigated barriers through co-creation. Few solutions for barriers have already been proposed [14]. With co-creation, students with disabilities and varying abilities can decide and influence which solution fits best for satisfying their needs and preferences. Moreover, students with disabilities can help to test solutions with assistive technology like wheelchairs, screen readers, or hearing aids. Synergies and other unexpected benefits (e.g. the curb-cut effect), as well as the avoidance of costs for remodeling the XR devices and applications once universal design becomes a legal obligation will make up for the additional co-creation costs in the long run.

The standardization process of the universal design of XR technology should be addressed. Namely, guidelines and best-case examples that designers and developers can use to create accessible and usable devices and applications need to be developed and compiled. These guidelines should include examples with specific implementations and source code. Moreover, user organizations, schools, municipalities, and authorities can use these guidelines to evaluate the level of universal design of XR alternatives during procurement. Likewise, the legislator can use the guidelines as a reference to define minimum requirements for developers and manufacturers.

There is a need to develop evaluation methods and tools to measure the degree of accessibility and usability of XR devices and applications. Such methods should indicate how well universally designed a specific device or application is compared to other equivalent candidates. These evaluation methods and tools would support user organizations, schools, municipalities, and public agencies during procurement processes by identifying the most universally designed competitor. Moreover, these methods and tools could assist XR developers and manufacturers during design, development, and testing. Evaluation methods and tools should be easily integrable into an agile development process, and most likely be automatable to some degree. Finally, evaluation methods and tools can compare and evaluate the effects of universal design against their level of conformity with the previously discussed standards. Evaluating effects could highlight gains and weaknesses, make them visible and uncover synergies and unexpected benefits in areas that might not have been originally targeted by an investigated solution. By improving the audio experience in the virtual world for students with vision disabilities, for example, one might improve the experience of students in general.

5. Conclusion

Even though XR technology in education offers a variety of advantages, especially for students with learning difficulties, the technology has a significant lack of universal design and a low degree of accessibility and usability for students with disabilities and varying abilities. Our findings from focus group interviews with representatives of XR companies, educators in schools, decision-makers in municipalities, and user organizations confirm many of the barriers that we have uncovered from a previously conducted selective and weighted literature search. Specifically, students with different degrees of sensory abilities, e.g., hearing and seeing, encounter barriers related to the lack of multimodality, lack of accessibility of the (graphical) user interface, and incompatibility with assistive technology. Likewise, physical barriers and limitations of the headsets can hinder students with physical disabilities and common conditions like wearing eyeglasses alike. We show that financial requirements from investors and missing guidelines likely hinder the implementation of solutions to mitigate barriers. Finally, we define five future research needs to facilitate the use of XR technology in education related to (1) *increased co-creation in the development of XR applications and devices*, (2) *identification of barriers for students with disabilities, as well as the (3) the development of solutions for said barriers*, (4) *the advancement of standards, guidelines and best-practice examples for increased universal design of XR technology in general*, and (5) the development of *evaluation methods and tools to measure the degree of accessibility and usability of XR devices and applications*.

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