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The Future of eXtended Reality in Primary and Secondary Education

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Abstract. eXtended Reality (XR) technology has to some degree been used in primary and secondary education. However, XR technology has not gained widespread use in public schools due to challenges related to pedagogical content, expertise, digital infrastructure, funding, and a lack of universal design. In this paper, we present the results from focus group interviews with representative stakeholders from the private and public sectors, in which we investigated their practical experiences and opinions about XR technology in Norwegian schools. We summarize the practical opportunities and challenges of using XR technology in primary and secondary education. We compare the results with a previously conducted selective and weighted literature review and extract four major future research needs to increase the practical and systemic universal design of XR technology in primary and secondary education for all.

Keywords. Digital Learning; Information and Communications Technology (ICT); Accessibility; Usability; Digital Infrastructure; Expertise; Funding; Pedagogics; eXtended Reality (XR); Primary and Secondary Education

1. Introduction

Numerous implementations of eXtended reality (XR) technology – comprising both virtual reality (VR), mixed reality (MR), and augmented reality (AR) – in primary and secondary education have been trialed and tested in the past decade [9]. Even though many positive effects have been reported, widespread integration into schools is hindered by a significant lack of universal design, especially for students with disabilities and varying degrees of ability [8]. Furthermore, several practical and systemic barriers limit its universal accessibility and usability.

In this paper, we discuss facilitators and inhibitors for ubiquitous access to XR technology in primary and secondary education. Relevant data were collected from the literature and focus group interviews with selected stakeholders from the private and public sectors in Norway. We identify opportunities, as well as challenges related to pedagogical integration, expertise, digital infrastructure, and funding. Moreover, we discuss future research needs to advance the universal design of XR technology in education, allowing everyone access, regardless of individual needs or abilities.

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2. Methodology

We invited 12 representatives from the private and public sectors in Norway to participate in three focus group interviews: (1) companies that develop XR applications for education, (2) educators from public primary and secondary schools, (3) decision-makers from municipalities, and (4) representatives from user organizations for people with cognitive (e.g., dyslexia), sensory (e.g., hearing and seeing), and physical disabilities in Norway. We guided a discussion with 2 to 5 participants during each interview, in which we asked participants to share and discuss their experiences and opinions about XR technology in primary and secondary education. We asked participants to focus on XR technology's advantages, disadvantages, universal design, barriers, and solutions to said barriers. Moreover, we investigated their opinions about the technology's need for future research. Then, we compiled a summary of the reported opportunities and challenges (cf. 3. Results). Finally, we compared and discussed our results with the findings of our selective and weighted literature research that we conducted beforehand [9], and identified future research needs (cf. 4. Discussion).

3. Results

3.1. Possibilities

XR is first and foremost technology for mediating experiential learning. XR can offer experiences that students would not otherwise have had. Such experiences might include trips to foreign geographical locations, historic places, or situations. In addition, students can interact with objects in XR that are too large (such as planets and solar systems) or too small (such as atoms and molecules) to be experienced in the physical world. Focus group participants reported that XR had given them a completely different impression and experience of a topic than they had without XR.

XR can elevate the learning experience of students by presenting the curriculum in novel and more engaging ways. Many students find XR to be new and exciting, and thus feel more motivated and engaged with the learning content when presented in this format. The feeling of immersion can stimulate children to pursue a topic for longer. XR can transform learning from a chore into a pleasure. Especially some students with cognitive disabilities and other special needs might benefit from XR [8]. Likewise, this can inspire students in creative tasks such as writing because experiences in the virtual world are as real as those in the physical world. One participant recounted a case where students were given the opportunity to travel virtually to the geographical location of an assigned writing task. This facilitated the student's writing process greatly.

XR can enhance practical aspects of a topic or concept. In XR abstract ideas, concepts, and contexts like chemical reactions or gravity, can be visualized and interacted with. In virtual reality, students can for example look at 3D models they have previously developed on the computer or investigate anatomical body parts and their functions.

XR can stimulate social interaction and collaboration. Local connectivity and online features allow students to interact and collaborate remotely with fellow students both locally and globally. Moreover, many virtual experiences in XR can be shared with the educator and students on a screen, either simultaneously or post-intervention through a video recording. By sharing the experiences, educators and students can reflect and discuss observations in a way that feels more real than when viewing them on flat 2D digital surfaces.

XR parallels the digitization of our society and is well suited to complement traditional teaching tools. XR technology reflects a world that is increasingly digitized, a process advanced by decision-makers like politicians, research leaders, and school leaders alike. The new teaching curricula in Norway focus on the need to increase digital competency in all children and encourage the use of digital tools that can mediate learning [12]. However, most educators emphasized that they did not want schools to base learning exclusively on digital teaching tools but wish to combine digital with traditional learning tools. Thus, XR technology should not replace traditional learning tools, but add a new element to the existing toolbox to enhance the curriculum and provide an opportunity to acquire knowledge by combining XR mediated with familiar learning. One participant presented the example of a textbook, in which virtual content was integrated through AR to create a pop-up book. The combination of virtual and traditional physical teaching tools is especially important for students with disabilities or varying abilities who cannot use XR as discussed in an article that has been reviewed elsewhere [8]. Thus, educators should have options for conveying the curriculum through different means to individualize learning.

XR can help improve digital skills in children. Considering the general digitization process in European countries, at least 90% of jobs in Europe require some degree of digital competency, but between 35 and 45% of the European population do not even have basic digital skills [1, 2]. Thus, the European Union (EU) aims to increase the percentage of its population that has at least basic digital skills to 70% by 2025 [2]. The Covid-19 pandemic has accelerated the digitization process: Schools established, for example, digital solutions and routines such as video conferencing systems for schooling at home. XR technology has become a part of this process, due to its improved availability to common consumers. Consequently, the use of XR technology has increased in various contexts, like gaming, traveling, or manufacturing. However, for schools to be able to take advantage of XR technology, their leaders and educators will need to be upskilled.

XR can advance alternative learning processes. The alternative learning model of *computational thinking*, promoted by the Norwegian Directorate for Education and Training (Udir), conceptualizes a learning process that encourages students to evaluate different steps to solve a problem [11]. This learning model aims to train students to learn and solve problems systematically by "thinking like a computer scientist" [11]. Students are expected to advance skills related to decomposition, logic, algorithms, patterns, abstraction, and evaluation through methods that involve trial-and-error, including playing, being creative, and troubleshooting, while also building endurance through collaboration and reflection [11]. XR technology is well suited as a complementary tool for mediating such learning processes via combining immersive technology with new ways of interaction, presentation, and experience through immersion. Computational thinking as a concept may also be transferred to educators. They may need to challenge themselves to become familiar and comfortable with when and how to implement XR technology in the best way: This includes becoming comfortable with not having the necessary knowledge and skill about the new XR technology. Similarly, students may learn that the learning process is more important than the results. One focus group participant pointed out that to succeed with XR technology and computational thinking, the educators themselves would have to experiment and trial-and-error with the new technology.

3.2. Challenges

Lack of educational content adapted to national curricula. Even though several Norwegian companies have developed educational software applications for the Norwegian market, there is still a lack of supply for most of the national curricula. Many XR companies in Norway are small start-ups with limited capacity and resources focusing on a few niche aspects or topics. Thus, some educators have found creative ways to reuse international software for their subjects. One educator reported using Google Arts & Culture [3] in writing assignments. However, some courses cannot be taught with international software because of a mismatch with the Norwegian school curricula or language barriers.

Educators lack digital skills in general and for XR technology in particular. XR is still new and, equipment and software are rapidly evolving. Hardware and software can seem complex and difficult for the beginner, and the focus group participants reported that manuals or guides were neither intuitive nor user-friendly. It takes time and effort to learn the setup, control, and navigate the software, and even more time to learn to customize it to suit one's individual teaching. Due to a high workload, many educators are not able to set aside time to learn about, experiment, or practice the usage of XR technology during normal working hours.

Educators with technology anxiety and skepticism towards XR technology. As mentioned above, XR technology is unknown to many educators and can seem complicated, complex, and overwhelming at first. Educators might experience that something goes wrong, they make a mistake, or that there are too many practical and technical uncertainties related to XR technology. Our focus group participants reported generational differences: On the one hand, younger educators were less afraid, more willing to try XR technology, and were not worried about needing to go through a phase of trial-and-error. On the other hand, the more mature educators expressed that they felt challenged in their role as educators, being afraid of losing face or control or appearing incompetent[2].

Systemic challenges due to the lack of digital infrastructure for introducing and maintaining XR technology in schools. XR has no institutional anchoring in primary and lower secondary schools to date. No national centers exist to support local and regional schools in getting started with XR projects, except for some regional centers [10]. Instead, many XR projects in schools are shouldered by highly motivated, enthusiastic educators. Once those enthusiasts leave their schools, their XR projects are put on the shelf. Moreover, there is no practical and technical infrastructure for XR technology in Norwegian school systems. There are no guides, manuals, or procedures for setup and maintenance. Login protocols often do not comply with school policies[3] which typically require a service for unified identity management in the Norwegian education sector called FEIDE [7]. Finally, the payment system of XR technology is not compatible with the accounting system of Norwegian schools, forcing many educators to pay for devices and applications out of pocket first before receiving compensation from the schools.

Costs related to the acquisition and maintenance of XR technology. XR projects require a substantial initial investment. However, there are vast economic and social differences between Norwegian schools, and many schools do not have budgets that allow

[2] We want to point out that there are elderly educators who have initiated and are leading XR projects and who, among other things, have learned programming for various XR platforms like Unity later in life.

[3] Oculus Quest II, for example, has previously required users to have a private Facebook profile to log on to the XR application leading to the creation of "fake profiles" [6].

for innovation and development of the scale needed for XR technology. In general, there are no established grants, structures, or schemes for financing XR projects. Some focus group participants pointed out that securing funds for digital projects was more challenging for primary schools than for upper secondary schools. Moreover, many XR platforms require the payment of ongoing licenses for maintenance. Likewise, some XR platform providers only offer enterprise solutions that are too expensive for public schools [5].

4. Discussion

4.1. Comparison between the literature and the interviews

The focus group participants emphasized that to make XR technology more accessible and usable for all, there was a need for further research and development to identify pedagogical opportunities and advantages, as well as disadvantages and limitations in a national context. A representative quote from an educator stated that *"to succeed with XR technology in the classrooms, a certain degree of time and patience is required"*. Moreover, the participants underlined the importance of developing practical guides, manuals, and procedures for the integration of XR technology into schools.

Our findings from the focus group interviews show many similarities with the findings of a selective and weighted literature search that we have conducted previously [9]. During this literature review, we found positive outcomes of using XR technology in education related to increased learning gains, improved social skills, improved self-image, facilitated emotional reactions, improved cognitive skills, and increased motivation, engagement, and interest [9]. Moreover, we uncovered challenges related to economic costs, physical space, health, pedagogy, editorial limitations, and lack of universal design [9]. On the one hand, the focus group participants mirrored positive aspects related to engagement, motivation, and interest. Furthermore, they gave practical examples of how experience-based learning can bring practical context to abstract educational content. On the other hand, the participants put a greater emphasis on challenges related to expertise, digital infrastructure, and funding, as well as accessibility:

First, technology anxiety and skepticism, and the lack of digital skills, experience, and familiarity with XR technology affect educator acceptance negatively. Low acceptance means in practice that educators are reluctant to try out or incorporate XR technology in their teaching. Thus, focus group participants emphasized the importance of developing guides with an educator of average digital skills in mind, rather than an early adopter. Moreover, traditional analog teaching tools must remain a viable option. XR technology should be an addition to, not a replacement of traditional teaching tools [8]. Second, financial, and digital infrastructure-related barriers might prevent educators from implementing XR projects in their schools. Many public schools have a limited budget, and digital tools compete with many other items for financial resources. Consequently, many schools will range the versatility of a teaching tool to be more important than potential gains in one singular topic. Thus, many schools will prioritize digital tools that can be used for various purposes, topics, and levels. Computers, tablets, or phones can be repurposed, while XR devices and applications today are limited and lack authoring capabilities. Likewise, the full potential of ubiquitous pedagogical integration and its effects remains under-researched. Some participants, however, suggested that the ongoing maturation and consolidation process of XR technology might diversify the possibilities and provide a larger range of XR devices and applications suited for education in the future. Moreover, they argued that investments in new equipment will always be necessary during the introduction phase of new technology.

Third, representatives of user organizations for people with disabilities have pointed out the need for making XR technology more accessible and usable for all. These barriers of XR technology exclude a significantly greater number of students than other digital learning tools, especially if used in default mode only. Technological challenges related to the accessibility and usability of XR technology have been reviewed elsewhere [8].

4.2. Need for future research

To make XR technology more accessible for schools, we must solve challenges around pedagogical integration, expertise, digital infrastructure, and funding. We argue that these suggestions are transferable from a Norwegian to an international setting. Moreover, discussion of a fifth need for increasing accessibility, usability, and general universal design of both XR devices and applications is also of importance [8].

4.2.1. Pedagogical integration and effects

There is a need to highlight and communicate both the educational opportunities of XR technology and its limitations. There is a need for more research on the possibilities and effects of using XR technology in schools. There is, for example, a lack of widespread research that measures learning outcomes and the long-term effects of technology in schools on a national and regional level [9]. There is a need for research that identifies the practical benefits and limitations of XR technology, as well as solutions to mitigate the limitations and possible synergies between topics and teaching tools.

Moreover, there is a need for implementation research on how to streamline and integrate XR technology with national curricula alongside analog teaching tools. There is a need for diversification of software applications that fit the national curriculum, as well as the development of guides and manuals to smoothly integrate XR technology into national and local curricula. Likewise, there is a need to develop and implement authoring methods that allow for easy editing and adaptation of virtual content to different topics/subjects and the individual educators' needs and learning styles. Moreover, there is a need to investigate the benefits and limitations of XR technology for various student groups, as well as the conditions that facilitate benefits and mitigate limitations.

4.2.2. Skill development and acceptance

There is a need to develop and improve the digital skills of educators and decision-makers to increase acceptance for, as well as lower the threshold for implementing XR technology in schools. Supporting educators in their role as an educator is important. XR technology is meant to complement existing analog and other digital aids, not replace them. The educator should always feel to be in the driver’s seat, and that they are the ones deciding if and which XR technology fits their teaching style for any given purpose. To allow educators to become familiar with XR technology, it could be useful for schools to be able to rent equipment such that the educators can test the XR devices and applications. It can make sense, for example, to let educators first play an unrelated game like Beat Saber to learn how to navigate inside and interact with the digital world. Local, regional, and national science, technology, knowledge, and competence centers could realize the introduction to XR technology by offering schools the rental of equipment.

Moreover, such centers could exhibit permanent XR installations for classes and educators to visit to familiarize themselves with the technology. Likewise, the centers could arrange events at individual schools or organize staff training sessions for XR technology to develop the skills of the educators.

4.2.3. Digital infrastructure and manuals

There is a need to create a digital infrastructure that suits the national and local school systems both technologically and methodologically. An infrastructure for integrating XR technology in education should provide practical and technical solutions to common challenges such as login or payment, rigging, and setup. In Norway, for example, it should be possible to log in to XR devices through FEIDE, a service for unified identity management in Norwegian education, or the respective system in other countries. Likewise, payment procedures for licensing should be developed that can be easily integrated into the schools' financial routines and procedures. Moreover, a guide or manual should be developed detailing requirements, preparations, and instructions for the setup and initialization of XR technology. This guide should include background information about AR, MR, and VR technologies in general as well as specific devices and equipment and explain how educators can set up the technology physically, install software, and provide instructions on basic functions such as settings or controls. This manual should be co-created with the help of educators to guarantee universal design for all.

4.2.4. Funding guides

There is a need to address the financial needs required to fund the acquisition of XR devices and applications. Schools often lack a sufficient overview of necessary equipment and their costs, as well as available funding schemes. Thus, we suggest a guide or manual that supports informed decision-making in schools. This guide should detail potential equipment including their price and versatility. The guide should also sketch out the limitations, indicate possibilities for multi-purposing, and highlight combination possibilities with traditional teaching aids. Moreover, strategies for funding should be discussed based on the experience of existing or past XR projects including (1) prioritizing funds in the current budget, (2) project funding through applications for grants from public authorities and agencies such as the Norwegian Directorate for Education and Training (Udir), regional research funds, or the municipalities, and (3) sponsoring by local businesses in the community like local savings banks or medium-sized companies.

Moreover, there is a need to address the economical, ethical, and practical realities within our society that can influence the procurement of XR technology. The education systems in most European countries like Norway are based on the principle of providing equal opportunities to all students regardless of background, social or financial status. However, financial differences between individual schools exist. This difference is potentially larger within and between other European countries. Thus, relying solely on external funding might give schools in a wealthy neighborhood/country with good contacts and ties to the local business community an advantage in raising funds to acquire XR equipment compared to a school located in an impoverished neighborhood/country. Likewise, it can be challenging to solely rely on students' mobile devices for the use of AR. Some students from low-income families might not be able to afford an expensive AR-compatible smartphone. Likewise, some schools might recently have procured tablets or smartphones that do not support XR-related software or hardware.

5. Conclusion

There is no doubt that XR technology offers some promising opportunities for primary and secondary education: XR is an experience-based learning tool that can provide satisfactory visualizations of abstract concepts and ideas. At the same time, there are certain pedagogical, skill- and acceptance-related, digital infrastructure-related, and funding challenges that we discuss in this paper. Moreover, we present four major areas for future research needs related to pedagogical integration, digital skills, digital infrastructure, and funding to make XR technology more accessible and usable for all: (1) *There is a need for pedagogical integration.* This includes developing strategies for integration with national curricula, content creation for a wider spectrum of subjects, as well as evaluation of pedagogical long-term effects. (2) *There is a need for allowing educators to develop their digital skills for this emerging technology in a non-threatening environment.* (3) *There is a need for developing technological and methodological digital infrastructure to smoothly integrate XR technology into school systems.* This includes developing procedures to more easily set up and use XR projects at schools. (4) *There is a need for supporting schools in the procurement and funding process of XR projects.*

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