Augmented/Virtual Reality in Nordic/Baltic Education, Learning and Training

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1.0 Executive Summary

During 2012-2017 I worked with a number of Nordic colleagues in two projects funded by Nordic Innovation to map out the emerging Nordic edtech industry (with a focus on startups), and to stimulate the creation of a Nordic edtech community. I have been very happy to see significant progress on this front since 2012, and today we have a vibrant edtech community in each of the Nordic (and Baltic) countries, and growing collaboration across the region. I see XR-Edu (Shorthand for "AR/VR in Education, Learning and Training") as an "emerging subsector" of edtech, and hope to see a similar evolutionary development in XR-Edu as we have seen for Nordic and Baltic edtech in general.

This report is a small step in the direction of both mapping what is happening across the Nordics/Baltics in the XR-Edu space, and to encourage knowledge sharing and collaboration—including sharing of "good/best practice" of XR-Edu applications—across the region. The project has had no external funding—an intentional decision to give me more "degrees of freedom" in terms of "the what, how and when" of the research effort—but it of course also implied some budget constraints in terms of what I could do.

I have been pleased about what Teele Jürivete (who has handled the Baltic region) and I have found during our "XR-Edu journey of discovery" through the Nordic/Baltic region, and I am encouraged about the future of Nordic/Baltic XR-Edu. The "guarded optimism" is based on what we discovered: A strong research foundation across the region, and a diversity of researchers in academic and industry organizations, active in range of different domains, either directly or indirectly connected with XR-Edu. A wide variety of XR-Edu projects have also been completed (and others are under way or being started)—as you will find in references throughout the report—although it is perhaps not surprising that relatively few projects have involved significant deployment of XR where students have used XR in their learning activities.

In a section before the "country sections" start, we felt a "global context" was needed, in order to provide a little bit of a "baseline" so activities in the Nordics/Baltics could be placed in a broader framework of trends and developments in other regions of the world. If you follow XR developments, you know there is a great deal of XR activity in all parts of the world, and, not surprisingly, large investments in either XR technology research, development or deployments, including in North America and Asia (especially China), but also in many other countries. The Global Context chapter only captures some of these developments, as well as some of the inevitable hype—excessive optimism—that we see in many studies and reports. Much of this can be found especially in the popular press and produced by various forecasting organizations. We feel we are all better served by realistically assessing what may lie ahead, to avoid exacerbating booms and busts that often are associated with new technology developments.

As noted in the early part of the report, we also feel it is beneficial not just looking ahead, but also look back and see what we can learn from examining past experiences with immersive technology, such as what we saw when "Virtual Worlds" (and especially Second Life) were in vogue. At the time, many large companies, including IBM, significantly overestimated what the platforms of those days could do (both in enterprise and education contexts), and how they would be used.

XR-Edu researchers and practitioners can benefit from watching and learning how real benefits can be achieved from the use of XR technologies in industries, like manufacturing, extractive industries, service industries, medical and health sectors, and others. And while projects in these industries tend to have larger budgets than those in the education sector, these applications are also very ROI (Return On Investment)-focused. XR-Edu supporters must also work hard to gain better insights into cost-benefit tradeoffs, so that we can show when better learning outcomes achieved with XR technologies are cost-

effective. This is done too seldom today, but needs greater focus in the future, if we want to convince educational decision makers to provide the capital investments and operational funding for future XR projects in both schools and universities.

The last couple of sections of the report identify what we see as some of the key issues, opportunities and challenges facing those working with XR-Edu, either directly or indirectly, and in a variety of jobs that can have significant influence on the success or failure of future XR-Edu projects. Open dialog among people working with XR will build a stronger knowledge base, especially if and when one can also leverage prior knowledge gained from projects in other parts of the world. Bringing such lessons gained to the Nordic/Baltic region, perhaps via new institutions that focus on providing more and better deployment assistance to those doing pilot XR-Edu projects, will improve the chance of project success, and in turn lead to more and better future XR-Edu projects throughout the region.

2.0 Preface

This report is a result of a small research project with no external funding and with a very limited budget, and has been researched over a limited period mostly during 2018. We have used a variety of sources, including our personal networks in the Nordics/Baltics and the US, and benefitting from a variety of online resources on past, current and future AR/VR activities and projects (Please note that hereafter in this report, XR will be used in this report for AR, VR and MR for sake of simplicity—see Box A). The main goal has been to identify interesting players and projects/activities in the Nordic/Baltic region, mostly early stage companies and some larger, more mature companies active in XR (such as EON Reality—see sections on Norway and Denmark). we also wanted to identify pilot projects of XR in schools or in universities, as well as XR labs and research projects in universities.

It is far beyond the scope of this limited effort to try to get a comprehensive map of players and projects focused on education, learning and training (again, for simplicity, we will from now on refer to this as Edu, and XR-Edu, as a way to capture all AR, VR, and MR in education, learning and training) in the Nordic/Baltic countries, but we hope that we have managed to identify many or most of the most interesting and significant projects, which in turn may become the foundation for more and larger projects across these the region. We plan to continue to monitor activities in this area as best we can, and hope to publish occasional updates of new and interesting projects and developments. Therefore, we would greatly appreciate any assistance you can provide, especially by:

- Sending me a note [email: eilif.trondsen@Siliconvikings.com] when you see information in this report that you feel is factually incorrect, or has been misinterpreted in some way. I also would greatly appreciate any other comments you have on the report, including critique and suggestions for things that should be done differently in future updates I hope to publish.
- We would be very grateful for any information about relevant and interesting XR-Edu projects in the Nordics/Baltics, that you feel should be included in this report or future updates, and it would be especially helpful if you could include any information such as names of organizations, project participants, or online links that have project descriptions, etc.

As noted above, we have benefitted from numerous phone and video conferencing calls with many good friends and colleagues in the Nordics/Baltics and the US. We am very grateful to all of you who took the time to share information and your insights. A special thanks to: Teele Jürivete (University of Tartu,

Estonia) who researched and wrote the section on the Baltics (5.5.2); Jonas Bostrom, Founder and CEO of EduChem VR in Sweden (who wrote Box J) and Per Olav Nyborg (VR Education, Norway) (who wrote Box I).

Also thanks to the following contributors:

Margus Pedaste (University of Tartu, Estonia); Märt Aro (Dream Apply and N8, Estonia); Søren Larsen (Roskilde University); Mikkel Marfelt (Director of Research Partnerships, Labster); Laura Salo (The Innokas Network, University of Helsinki); Sirkku Lahdesmaki (University of Jyväskylä); Tiina Korhonen, (The Innokas Network, University of Helsinki); Timo Lindqvist (Upknowledge, Finland); Aki Puustinen (Muurame Senior High School); Jon Brochoud (Arch Virtual, US); Matthew Hasel (TriPoint Lab, US); Linda Jacobson (Set It Spinning, US); Mats Johansson (EON Reality, US); Emily Olman (VR/AR Association and Spatial First, US); Michael O'Rourke (Immersive Learning Center in Vallejo, CA, US); Anders Gronstedt (Gronstedt Group, US); Lisa Castaneda (Foundry10) Are Vindfallet (Making View, Norway); Knut Henrik Aas (EON Reality, Norway); Håvard Røste (All Things Digital, Norway); Ekaterina Prasolova-Forland (VRLab, NTNU, Norway); Marit Berg Strandvik (Game School at Inland Norway University), Marcelo Milrad (Linnaeus University, Sweden); Per Arne Lundberg (GoodByeKansas, Sweden); Niclas Johansson (VRSverige, Sweden); Joakim Laine (University of Helsinki)

3.0 Introduction

3.1 "Why This Report" and "Why Now?"

Many of you who read this report may have asked yourselves the same questions my friend Mart Aro, Co-Founder of Nordic EdTech Forum (N8)[1] asked me some months back on the N8 Facebook page. Here are some of the reasons for why I felt a need to tackle this topic:

- I see XR as an emerging "subset" of edtech (an area that I have focused on for many years) and I am interested in "mapping out" what is now happening on this front in the Nordics/Baltics (the area of focus on Silicon Vikings), identifying interesting/ emergent projects/pilots and what various players are doing in the XR area.
- I am also seeking a better understanding of what the (realistic) possibilities/benefits could be for use of these "Edu technologies" as well as what challenges may lie ahead.
- As with any emerging tech, there is quite a bit of hype in the media about XR, and I hope to go beyond the hype and make an objective assessment of what we are likely to see in this area in the future, esp the next 5 yrs or so. I see myself as a realistic/pragmatic and optimistic observer/analyst when it comes to edtech or XR-Edu. And while I also play a bit of a evangelist role, I try to avoid hype.
- I am hoping this report will help create a knowledge foundation, with information, data, analysis and perspectives on XR-Edu throughout the Nordics/Baltics and that this will help stimulate knowledge sharing and ongoing dialog and conversation (and hopefully some debate), and perhaps help to create, at some point, a Nordic/Baltic Forum for XR-Edu.

Here is some of my thinking and reasoning for why I needed to write this report now:

[1] https://www.nordicedtechforum.org/

- In 2012 I approached Nordic Innovation and suggested a study of Nordic Edtech (which led to the funding of "Nordic Edupreneuring" project funded in 2013, looking at the emerging Nordic edtech industry), as I saw signs of the global edtech industry "taking off" and I felt it was the perfect time to start "mapping" out the Nordic edtech scene. I also wanted to stimulate cross-border knowledge sharing (across the Nordics) about edtech and encourage collaboration and building a Nordic edtech community (and today we now have much greater Nordic edtech collaboration and branding).
- I suspect we might be at a similar stage now for XR, where the emergent XR technology industry (probably a bit more emergent than the edtech industry was in 2012) is starting to create visions of new forms or immersive experiences of Edu, through the use of XR technologies.
- The general XR industry is in the middle of a rapid transformation, with significant technological (hardware and software) advances being announced every week and month. So, in terms of technological possibilities (i.e. the "supply side" of the equation), developments are very impressive, and prices of the technology is falling steadily, making the XR devices more affordable.
- The "demand side" of the XR-Edu equation is more uncertain, at least so it seems to me, even in the overall XR industry, even though growing numbers of both consumer and, perhaps general enterprise/industry applications are appearing regularly in the popular press. But the focus of this report, applications to Edu are much more scarce (but interesting developments are emerging) and lots of questions and issues still need to be addressed, but even here there are interesting new developments, and these are some of the things I want to explore in this report.

The vision and goals I have for the report therefore include the following:

- Create greater awareness of what is happening around XR, specifically around Edu in the Nordics/Baltics, in particular, and thus hopefully creating a better foundation for a more informed and educated examination of how XR may best find application that result in better learning outcomes.
- Stimulate collaboration projects across sectors, including industry and academia (K12 schools as well as higher education) and the public sector (municipalities, provincial agencies and education Ministries and other public agencies with activities related to education, learning and training). The RUC XR initiative in Denmark (see section 5.1.1), for instance, should ideally stimulate greater Nordic/Baltic collaboration, perhaps focused initially, or in part, on XR in STEAM learning (i.e. science, technology, engineering, arts and mathematics). I applaud the initiative that Danish educational policymakers have launched, and hope it will encourage other policymakers across the Nordics/Baltics to explore similar initiatives and to learn from and leverage the RUC initiative and the insights and lessons that will come out of that initiative.
- Knowledge sharing across sectors and cross borders, in order to highlight and share "best practices" and avoiding waste and avoidable problems that early adopters and practitioners in some parts of the Nordics/Baltics can benefit from, and in this way better develop high quality products and services that will enable Nordic/Baltic education and learning product and service providers gain global competitive strength against bigger, international players. Again, the RUC initiative could potentially and hopefully be an example of what benefits Nordic/Baltic knowledge sharing could yield, and perhaps help enable "next-generation tech-enabled learning."

Box A

Definitions and Terminology

AR: Short definition: AR overlays virtual information/objects on the real-world environment. Not immersive or "isolating" as VR.

AR: Longer definition*: "AR is an interactive experience of a real-world environment whereby the objects that reside in the real-world are "augmented" by computer-generated perceptual information, sometimes across multiple sensory modalities, including visual, auditory, haptic, somatosensory and olfactory. The overlaid sensory information can be constructive (i.e. additive to the natural environment) or destructive (i.e. masking of the natural environment) and is seamlessly interwoven with the physical world such that it is perceived as an immersive aspect of the real environment."

VR: Short definition*: Virtual Reality is the use of computer technology to create a simulated environment. Unlike traditional user interfaces, **VR** places the user inside an experience (i.e. immersive).

VR: Longer definition*: Virtual reality is an interactive computer-generated experience (enabled by a Head-Mounted Display, HMD) taking place within a simulated environment, that incorporates mainly auditory and visual, but also other types of sensory feedback like haptic. This immersive environment can be similar to the real world or it can be fantastical, creating an experience that is not possible in ordinary physical reality.

360-degree Video: Short definition: Also known as immersive videos or spherical videos, are video recordings where a view in every direction is recorded at the same time, shot using an omnidirectional camera or a collection of cameras.

360-degree Video: Longer Definition[2]: With 360-degree video, you're like a passenger in a car. You can look around and enjoy the curated scenery. But you can't, as in VR, decide where you want to go. But you may have some degree of interaction of content in the video[3] via hyperlinked content in preset locations in the video.

Two other acronyms are also frequently used in articles or reports that explore AR and/or VR. One is MR, denoting Mixed or Hybrid Reality, and defined as "merging of real and virtual worlds to produce new environments and visualizations where physical and digital objects co-exist and interact in real time." Finally, XR denotes Extended Reality and refers collectively to AR, VR and MR[4]. For sake of simplicity, we will use the term XR in this report, although today most XR-Edu is primarily using VR technology. However, when it is appropriate to refer specifically to AR or VR, we will use these terms.

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[2] "Demystifying 360 vs VR" by Dana Staff

[3] In a December, 2018 paper by Romain Christian Herault, Alisa Lincke, Marcelo Milrad, Elin-Sofie Forsgärde, and Carina Elmqvist. "Using 360-degrees interactive videos in patient trauma treatment education: design, development and evaluation aspects," they are proposing a system that in which "Various types of interaction mechanisms are integrated into the video to which learners can act and respond. The learner's navigation (via Google Chrome browser) in the video and the interactions with the content are saved in cloud storage, so these data sets can later be processed for further analysis."

[4] I have chosen to not add Virtual Worlds (VWs) here, but a brief discussion of this form of virtual platforms—very popular about 10 years ago—is found in section 2.2

In general, the term XR would of course apply to a wide range of applications, across many different sectors and industries (including health care, marketing, entertainment, and enterprise applications)—as noted in section 4.5 of this report—but the focus and scope of this report is on "education, learning and training", and we will try to use the term "XR-Edu" to make this distinction clear.

* Source: Wikipedia

3.2 Calibrate Expectations

It is interesting to look back in time and review and reflect on what we have experienced and learned over the years about the use and impact of technology in education, in particular, i.e. how technology has been expected to change the way education is delivered (and "consumed"). It is not hard to find plenty of examples of lofty expectations of a new technology—radio, television, computers (including laptops, tablets, smart phones), and Virtual Worlds (VWs), for example. Almost without exceptions, very smart and well-known individuals (like Peter Drucker, among them) have made predictions of dramatic impact, including (painful) disruption, by new technologies on the process of education and educational institutions. But the actual impact, or the time it has taken to see significant change, has been far less dramatic than expected.

I remember vividly the considerable excitement that many (including myself, I must admit) had about the expected impact of virtual worlds (VWs) around 2007 or so, when Second Life appeared frequently on front pages of popular news magazines, and discussing how virtual world would have dramatic impact across a wide range of sectors and industries, including education. Companies like IBM had thousands of employees creating avatars and having meetings and gaining interesting experiences in Second Life. And the company behind the platform, Linden Lab (in San Francisco), saw growing number of competitors building platforms[5], especially for enterprises that expected to move much of their corporate training onto these virtual platforms. The Norwegian oil company, Equinor (then Statoil), built a virtual oil platform ("in the North Sea") and tested emergency response training in this virtual environment, for instance.

Many universities and other organizations also tested out the Second Life or other similar platforms, and many expected these platforms to gain common use, and some observers/analysts expected VWs to dramatically change how education would be delivered in the future. And while many academics still find Second Life interesting and useful for certain things, the overall use of VWs has declined significantly as the benefits of using the platforms were not sufficiently compelling and outweighing the disadvantages/costs. And today we hear very little about IBM or other large corporations doing any significant part of their training in these kinds of VWs. And most of the practitioners who were very bullish and enthusiastic around 2006-2008 have moved on, and many are now exploring other new, emerging technologies such as XR.

3.3 XR-Edu Skeptics

[5] These included Wonderland (Sun Microsystems), Cobalt/Croquet, Olive/Forterra, Protosphere, Mondus, Active worlds, Vivaty and a number of others, many focusing on corporate users. Second Life probably had the most users from academia, and many continue to use the platform.

Many of the people who were skeptical about VWs a decade or so, now seem to be expecting XR to follow a similar hype curve to what we saw for VWs—although the hype of XR, especially in Edu, has not reached nearly the same height we saw for Second Life and other platforms about a decade ago. A recent article in Inside Higher Education, entitled "Does the Magic Leap One, and the Promise of AR, Matter to Higher Ed?". The author, Dr. Joshua Kim, Director of Digital Learning Initiatives at the Dartmouth Center for the Advancement of Learning and a Senior Fellow for Academic Transformation, Learning, and Design at Georgetown University, is typically not as much of a "edtech skeptic" as someone like Audrey Watters[6], but in this article he makes a number of comments that likely represent how many academics feel about XR. Here are some quotes from Dr. Kim to illustrate his concerns (which all XR enthusiasts/supporters) should reflect on and discuss:

- Augmented reality is not going to improve access to higher education.
- Augmented reality is not going to do that much to advance learning
- Augmented reality is not going to lower the costs of higher education.
- None of these technologies [AR, MR, and VR] will be very important for higher education.

Although most of Kim's focus in on AR, the last quote shows he doesn't think much of VR either, in terms of having a significant impact, at least on higher education. And I suspect that many in the XR community will disagree with Dr. Kim, and point to studies that show apparent positive learning outcomes when VR is used (AR studies are more sparse so far). And as we will see later, when discussing players and developments in Denmark, we will see how Labster's executives, as well as education policy makers as well as university leaders in Denmark, are more bullish than Dr. Kim. And Labster can point to use of its platform, and very positive experiences by many world-class universities around the world, especially for teaching and learning (laboratory-based) science. Table 1 below summarizes some of the potential benefits, as well as potential disadvantages/obstacles/challenges for XR-Edu technologies.

Table 1

Summary of Pros and Cons of XR-Edu

	Augmented Reality (AR)	Virtual Reality (VR)	360°-Video
Pros: i.e. Potential Benefits			
	Augments learner's perspective by adding data and information	Can create learning situations would be unsafe or impossible in "real world"	Allow students to learn to become video-based story tellers, using simple tools
	Can introduce dynamic content to result in deeper learning	Educators can design learning processes that enable deeper learning	Creates more engaging learning opportunities for students
	Can create interactive learning opportunities	New options for collaborative learning can be created	Gives student opportunity to become more active participant in learning activity
Cons: i.e. Potential Disadvantages/Obstacles/ Challenges			
	Time, effort and money to provide technologies needed	Same as for AR but perhaps to greater degree in VR	Same as for AR and VR but to lesser degree
	Many teachers may be reluctant to have to use unproven tech	Same as for AR but perhaps to greater degree in VR	Same as for AR and VR but to lesser degree

[6] Audrey Watters, the author of The Monsters of Education Technology, and a frequent writer, speaker and commentator on (US) educational technology developments, is almost always highly critical and negative about most, if not all, education technologies and is especially dismissive of Silicon Valley technology companies and venture capitalists who fund these companies.

	Rapid obsolescence of technology and cost implications	Same as for AR but perhaps to greater degree in VR	Same as for AR and VR but to lesser degree

Source: Eilif Trondsen, Silicon Vikings

Table 1 presents a very "high level" and simplified perspective on some issues that require much more detailed examination by anyone who wants to better understand what XR-Edu can do to improve education and learning processes and learning outcomes. For specific education and learning contexts, for particular curriculum areas, for instance, an indepth assessment is needed to explore what advantages could be had by using XR technologies, and whether AR, VR or 360°-video would be most appropriate. School administrators and teachers jointly need to ask these questions and draw on what others (perhaps in other parts of the world, where XR deployments have been made) have done and learned, and thus taking advantage of existing "best practice" and lessons learned.

Another factor that brings additional complexity is what costs, fixed and variable, will result from bringing XR technology into education and learning environments. Even more complex is to relate the additional costs (that will inevitably result) to what improvements in learning outcomes will be achieved. Measuring these and then figuring out what "Return on investment (ROI)" can be achieved with the new technology, is far from an easy task, and also, unfortunately, something that is seldom done. I have reviewed numerous reports and articles on XR-Edu and very few address cost issues, and this is especially true of ROI considerations.

4.0 Global Context

It is (far) beyond the scope of this report to attempt a comprehensive summary of global XR industry developments. But since Nordic/Baltic XR-Edu developments will be affected by, directly or indirectly, what happens globally—especially by hardware and software as well as content trends driven by large US, Asian and European players/markets—I thought I would at least highlight a few of the most interesting and important developments I have seen on this front. New developments are of course happening continuously, so updates of the report will contain new developments of interest, with focus on those issues and developments I feel will have most relevance for XR-Edu.

If you are interested in XR developments, there are plenty of news and information sources[7] that can quickly fill your email inbox. Most of them tend to focus on the following:

- New product and capabilities of XR hardware (HW) and software (SW)
- Spending forecasts—which of course are of great importance to both HW and SW vendors
- Venture and enterprise funding of XR startups—which show in part degree of optimism about the future of XR in terms of business opportunities

[7] Here are just a few that might be of interest (in addition there are of course websites that focus on XR developments and there are great bloggers who write regularly about XR developments): Inside VR/AR; VR/AR Association Newsletters; VRScout; Venturebeat AR/VR

- New tools and technologies for content creation—making it easier and perhaps cheaper to create content (and thus help "democratize" content creation, which in turn should help reduce content cost and increase content choice)
- New and interesting application areas and use cases

I will briefly highlight some of what I have seen as a few of the more interesting developments in each of these categories.

4.1 New Product and Capabilities of XR Hardware (HW) and Software (SW)

It is not surprising that much of the attention on this front focuses on headsets developments, including the latest innovations and functionalities of Head-Mounted Displays (HMDs) and especially the leading VR products including the following: HTC Vive, Oculus Rift/Go/Quest (Facebook), Samsung Gear, Google Daydream View, and Playstation VR (but smaller and emerging players are expected to become active players in this HW segment, especially at the low end[8]). HMD vendors continue to improve the quality of their product to improve the user experience—by adding more powerful technology (processing power, better optics, etc)—and offer HMDs at lower prices. Due to growing competition and perhaps weaker than forecasted consumer demand in 2017 (and even 2018), this has put downward pressure on prices, and this may continue depending on the balance between HMD supply and demand in various markets.

The last year has also seen growing focus on developing wireless HMDs, to free users from being tethered while using VR. As noted in one publication on XR, Road-to-VR, "Eliminating the tether on high-end VR headsets is an obvious desire with no obvious solutions. The issue comes down to three major factors: bandwidth, latency, and price; needs unmet by prior wireless video technology, which is why the big three high-end VR headsets that hit in 2016—Oculus Rift, HTC Vive, and PSVR—all rely on a cable which runs from the headset to the host machine[9]." A number of manufacturers are now offering or planning to "cut the cable", using a variety of technologies to make high-end VR wireless. When 5G, a wireless standard that are driving investments in all the major telecom companies, becomes common in the next few years (deployments gaining speed in 2019 but with significant market penetration in 2020-2021), all wireless technologies and use cases should benefit significantly.

On the AR side of HW developments, there is also a growing number of impressive players/products (some of which allow for MR, or switching from AR to VR, or the other way around, by altering the HMD configuration), enabling increasingly enjoyable user experiences. Some of the new HMDs allow users to easily manipulate virtual objects without the need for special gloves. Meta (a San Mateo, California, startup[10]) is one of these impressive AR players, but others include Google (now focusing its Google Glass on industrial applications), Microsoft (Hololens), and Magic Leap.

AR is generally seen to be a bit behind VR in terms of market awareness and adoption—especially in terms of Edu, at least right now—but many analysts see even greater, overall market opportunities for AR

[8] Already, many small Chinese startups have emerged (and many may also disappear). In a mid-2017 Global ARVR China Summit in Shanghai, there were dozens of companies specializing in XR. Interestingly, in Norway, a startup Moviemask (recently renamed to Ludenso, and released a new product, MagiMask, an easy-to-use AR package for all smartphones), which launched following Indiegogo funding, is now considering education and learning as a target market.

[9] https://www.roadtovr.com/5-wireless-vr-companies-htc-vive-oculus-rift-technology-overview/

[10] Due to financing issues resulting from a major Chinese investor pulling back on its planned investment (due in part to US-China trade conflict) has created uncertainty about Meta's future product plans.

than VR, and many think that Apple could enter the AR industry (in a big way) in the next year or two. And it is no secret that Apple is very bullish on AR, as their CEO, Tim Cook, has made very clear that he thinks AR will be a huge opportunity—perhaps as an eventual successor, or major complementary technology, to the iPhone. Microsoft's Hololens is also an impressive headset that has gained positive enterprise market reception (and, as noted later in this report, the US Department of Defense has recently showed strong interest in this product), but is currently too expensive for many consumer markets.

Magic Leap has gained most attention in the AR space, in part because of its own heavy (self) promotion but also by raising the most money—which according to Crunchbase, has so far raised $2.3 Billion dollars in 5 funding rounds so far (and with lots of "heavy weight" investors—as well as using some of their funding to acquire other players with interesting technologies (two companies in 2016 and two in 2017). The much anticipated release of their first HMD in August 2018 had a very mixed reception, however, but perhaps a natural result of their own hype and building up unrealistic expectations for their first product. The company is now offering grants to organizations, including educational institutions that can develop attractive AR solutions, using Magic Leap's headset.

From a Nordic perspective, it is also quite interesting that Magic Leap—which has its HQ in Orlando, a burgeoning gaming and graphics hub (with one of the biggest video game development communities in the US)—is now looking to the Nordics, and specifically to Finland, for talent and technology that could help them in their pursuit of building the best AR HMD in the world (see Box below that summarizes what strengths Finland has of interest to Magic Leap).

Box B

Magic Leap Seeking AR Tech in Finland

According to the Techcrunch article on "Magic Leap Goes to Finland in Pursuit of Nordic VR and AR Talent," the article notes:

- "Today Finland's gaming startups along with companies in hardware, software, and optics are attracting the attention of global players"
- "The country boasts a wealth of corporate knowledge in all of the fields that would be relevant to the next breakthrough in optical technologies. Whether photonics design and manufacturing (Nanocomp); X-ray cameras (Advacam); ALD (Picosun, Beneq); camera tech (Nokia, Microsoft); spectral imaging (Specim, Spectral Engine) optics manufacturing (Oplatek, Millog); laser tech (Cajo, Primoceler); automation (OptoFidelity), QA (Helmee Imaging) or silicon photonics (Rockley Photonics), the state of the country's optics ecosystem is strong

Stockholm is also known as a very strong and leading Nordic gaming hub, but as will be described in section 5.3.1, the Hamar region of Norway has also built up a gaming hub which attracted EON Reality—a world leader in Virtual and Augmented Reality based knowledge transfer for industry, education and entertainment—and has helped build a private-public partnership and XR hub around Hamar.

4.2 Spending on XR Products and Services

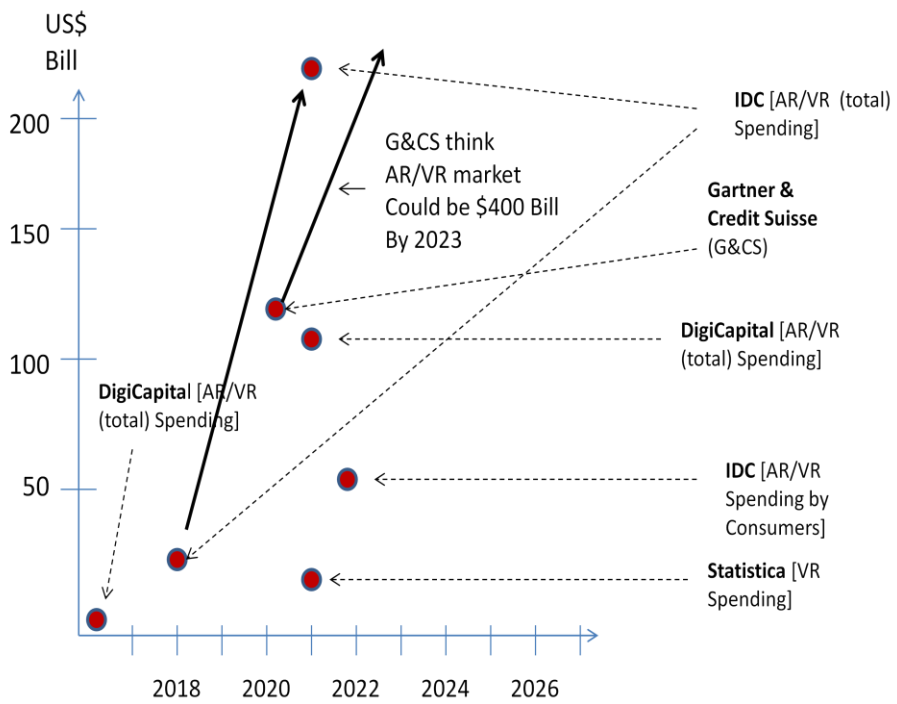
The roots of VR (and AR) go back many decades, and technologies for VR advanced at Atari, Xerox PARC, NASA and VPL in early days of Silicon Valley (and Jaron Lanier incorporated VPL in 1983), but commercial excitement has grown significantly during the last five years or so. Many analysts had expected to see 2016 or 2017 to be the “breakout” year for VR among consumers, especially for entertainment/gaming, but this did not really materialize quite as expected.

One VR observer, Wagner James Au, put mid-2018 forecasts of Oculus Go (the untethered Oculus product) perhaps selling 1.8 million of its $199 HMDs units in 2018, and also put this number in perspective by noting that video consoles typically sell 2-3x this number, despite costing 2-3x the price of the Oculus Go. HTC has countered the “weak VR spending” reports in the media, by noting that their products have been selling well, and as expected. But there is general agreement that XR are still “emerging technologies” and most users—either consumer or enterprises—are “early adopters”, and the overall XR industry is still tiny. DigiCap--one of the US analyst firms that provide estimates of current spending on XR as well as spending forecasts—estimates that the total XR spending in 2016 was less than $3.0 Billion. International Data Corporation (IDC)—another major market intelligence firm that covers XR—is much more bullish, and estimates the total XR market in 2018 to be around $25 Billion.

As shown in Figure 1, current spending estimates by market intelligence firms vary greatly. But forecasts for future spending show even great difference of opinion—although some of the differences may be due to different definitions of what is included in the forecasts. A notable bullish forecast from IDC shows growth from around $25 Billion in 2018 to $230 in 2021. A recent report (December 2018)—*Artillery Intelligence Briefing: XR 2018 Lessons, 2019 Outlook*—shows Global XR Revenues rising from $3.8 Billion in 2017, to $17.8 Billion in 2019, and $56.4 Billion in 2022. Interestingly, Artillery shows the following breakdown of its 2022 forecast: (1) Enterprise AR: $28.5 Billion; (2) Consumer AR: $16.5 Billion; (3) Consumer VR: $8.6 Billion; and (4) Enterprise VR: $2.8 Billion.

Figure 1

XR Spending—Analysts Estimates

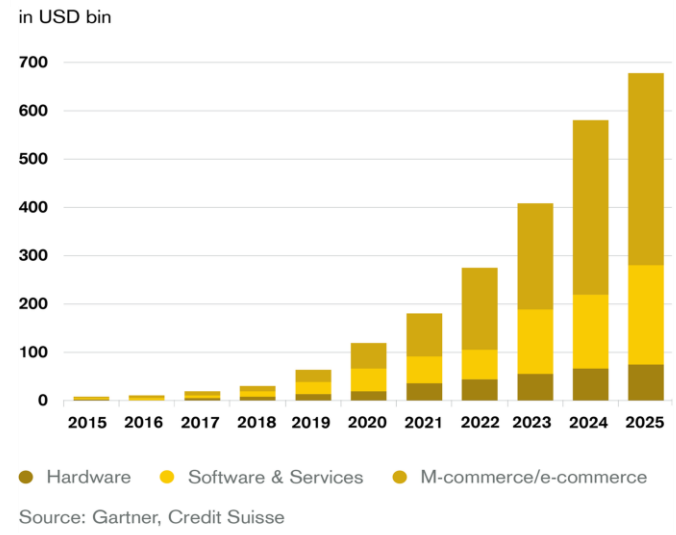


Source: Compilation by author
Using various public sources

Figure 2 below shows some of the thinking behind Gartner and Credit Suisse's very bullish view of the future of XR—with estimates that far exceed those of ARtillery. The figure disaggregates the Gartner/Credit Suisse forecasts into three major components: (1) Hardware (HMDs and related products), (2) Software (presumably including software-based content for VR gaming), and (3) Mobile and e-commerce. For the period 2020 to 2025, and presumably beyond 2025, the latter category will be where most of the spending on XR will take place, at least the way Gartner and Credit Suisse sees future XR adoption and use (more on this, including Edu applications, below).

Figure 2

Gartner & Credit Suisse XR Market Forecasts



https://www.boost.vc/?mc_cid=4decccf60&mc_eid=34b4c41397

4.3 Enterprise and venture funding of XR startups

Large technology companies—including all the FAGMA (Facebook, Apple, Google, Microsoft and Amazon) players—are all active in XR and making steady investments, either via interesting acquisitions or developing existing products and platforms (or content):

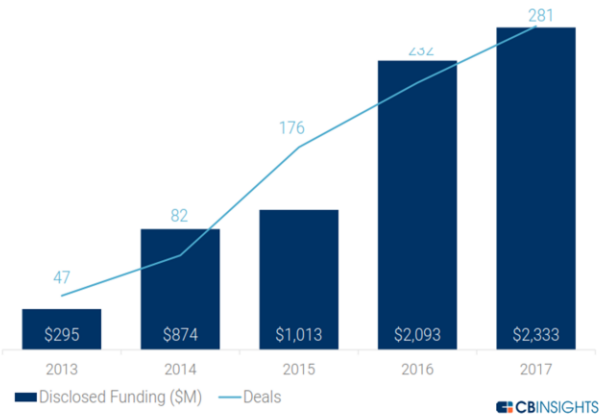
- **Facebook**: Acquired Oculus in mid-2104 for about $2 Billion, and has continued making investments in new and improved versions of Oculus. Worth noting in view of this report's focus on Edu, Oculus has an education group and has been providing grants to education XR researchers at universities.
- **Apple**: Has made at least 4 investments, mostly focused on AR (including the leading AR developer at the time of the acquisition (in mid-2015) of Metaio, a German firm started in 2003, as a offshoot from VW. Apple's CEO, Tim Cook, has made it very clear he is bullish on AR's future.
- **Google**: The company has made at least 5 XR acquisitions, according to CBInsights, and has been active for a number of years with both viewers (Google Cardboard), operating system (Google Daydream), and content/experiences (Google Experiences)—and given the company's considerable interest and activity in education and learning, it opens up interesting future options for the company's strategic direction with XR. (See section 5.1.2 on Google's VR collaboration with Labster, to enable "next-generation science education.")
- **Microsoft**: The Seattle-based tech giant is very active with developing its Hololens product, in particular. Hololens has found interest in many industry applications, and is one of many AR platforms that is gaining growing interest in the medical field, especially for medical and health education and learning, but also for preparing surgery and other medical interventions. But the US Defense Department, always an early adopter of many technologies, is now gaining strong interest in the potential use of AR. In late November, 2018, Inside VR & AR reported that "The U.S. Army has granted Microsoft a $480 million contract to supply more than 100,000 prototype AR headsets based on its HoloLens device."

- **Amazon**: One of its interesting activities in the XR space is Sumerian, a platform that has gained strong developer interest for building XR and 3D applications (and which leverages Amazon's Web Services platform—the company's "cash cow," which has seen rapid growth). The company has recently made interesting expansion into learning and training, especially for corporate learning (but could easily and quickly go far beyond just corporate training) and in this context, XR could gain additional interest inside Amazon.

The CB Insights figure below shows significant increase in capital invested in XR over the last five years but it is important to remember that during the last three years or so, Magic Leap has taken an outsized share of capital going into the XR industry—with rounds/deals of $542 million, $794 million, $502 million and $461 million since early 2015. The very large role, and great deal of hype around its products, have caused some in the industry to argue that the company has "sucked all the air out of the room" (i.e. leaving little funding for other XR companies).

Figure 3

XR Annual Financing History



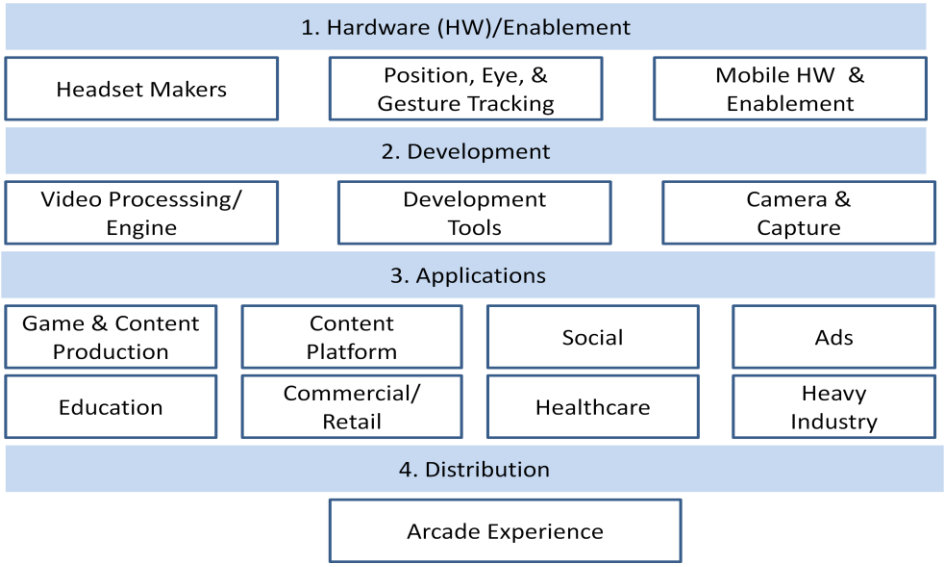
Relative to FinTech and many other emerging tech areas, XR is still small, but with growing interest (but likely to still see ups and downs in quarterly VC investments), especially if and when both consumers and enterprises start XR spending as laid out in the most optimistic scenarios of market intelligence firms noted in Figure 1. And since this report is focused on what is happening in the Nordic/Baltic region, it is interesting to see that the number and value of VC investments in this area are also showing significant growth, at least over the short time-horizon covered by Neil Murray (Nordic Web). Again, while XR investments lag significantly behind that of sectors like fintech, enterprise, and entertainment, the amount of money invested in Nordic XR per year increased from zero in 2014, to $47.4 million in 2015, and $189.5 million in 2016.

No detailed breakdown of the Nordic XR investment is available, but based on the reporting by Neil Murray and other reports on where money is mostly invested in VR, or AR (very little seems currently focused on AR), most of the money is destined for the "Game & Content Production" in the "Applications"

layer of CBInsights XR Stack shown in Figure 4. While we know relatively little about the money being invested specifically in the education category of the CBInsights XR Stack in the Nordics/Baltics, some references to XR activities by industry/sector category will be made in section 5.0 focusing on individual countries.

Figure 4

CBInsights XR Stack



Source: SB Insights

4.4 Content Development and Tools

Looking back to VWs, one of the aspects of Second Life that helped make it a very popular platform, and to grow rapidly, was the amount of content that was available on the platform, much of which, at least from my perspective, was of pretty high quality. Another perhaps equally important element of Second Life, was the range of relatively easy-to-use tools for residents on the platform to create their own content. In fact, one of the most interesting aspects of Second Life was the vibrant entrepreneurial activity that existed on the platform, resulting in many residents gaining significant income from using the tools (that Linden Lab made available and others that 3rd party developers built) to create a wide range of content, including clothing—so one could properly dress one's avatar—that enabled a growing Second Life fashion industry.

4.4.1 Content Quantity and Quality

For XR-Edu, having a wide range of high quality, low-cost content, will likely help build interest and XR deployment, as it will make the learning experience more engaging and enjoyable (just like the quality of

XR games is key to their appeal). And since most schools and universities tend to lack the resources that many enterprises have, cost will likely be a significant factor in any consideration of XR-Edu adoption.

To help kickstart XR-Edu, a strong and growing amount of XR-Edu content would be important, and a growing content developer community already has emerged, but the amount of high quality XR-Edu content is still not plentiful. The largest part of the XR community in the Nordics and Baltics today consists of XR studios, most of which are currently mainly targeting gaming. But most of them also advertise themselves as creating content for Edu (and other industries and sectors). These studios are mostly in the custom-content market, however—rather than creating content for sale in 3rd party markets—and thus would likely see relatively little business from the Edu sector.

In terms of 3rd party content, specifically of interest to Edu, here are just a few examples of what is now available (but none of which is yet Nordic/Baltic-specific, perhaps as the market is still too small, but hopefully this will change in the not-too-distant future):

- *Google's Expeditions*. Over 900 VR expeditions now exist, giving most teachers and students a wide choice of topics and issues to choose from. And the apps can be used with Google's Expeditions App, mobile devices or Chrome OS, as well as via Cardboard or Daydream[11]
- *National Geographic*. National Geographic is a renown content generator, but mostly known for its print media. But it is now, as many others, moving into "next generation media," and has teamed up with Google's YouTube to create a VR series.
- *Other publishers*. While many traditional media companies have faced challenging financial situations as a result of losing significant ad revenues online to Google and others, many—like New York Times—are still testing new media, including XR, and creating content that would be of interest to Edu.
- *Xdu-XR players with content offerings*. Organizations like Lighthaus--which creates immersive, interactive learning experiences for healthcare and the sciences—are now building content that is directed specifically at the Edu market. In many cases, they negotiate prices based on the specific needs and budgets of schools.

4.4.2 Cost and Price of Content

For XR-Edu, having a wide range of high quality, low-cost tools would enable students (and teachers/professors) to modify 3rd party content, or, ideally, create their own content. But it is important to realize that modifying or creating original content is far from simple. Even as relatively low cost cameras and other tools are now available to create 360° video, experience shows that creating high quality content of this type is also challenging, especially without significant training (which in turn requires time and money, both of which are scarce resources for most teachers). But, one of the ways in which future education and learning could improve, is to move students from mostly consumers of content to become more active participants of the learning process, especially by "learning-by-doing". This might also decrease the need for summative assessment (typically at the end of a course), and instead have student demonstrating skills and competence by what they have done/built/created. This would also enable students to become knowledge creators. A wide range of high quality tools and technologies would help support this move (and one that aligns the new learning environment with what the "maker movement" is trying to achieve).

[11] See discussion of Google Daydream in the section of Denmark's Labster, which has formed a strategic partnership with Google.

The scenario laid out above will take years to realize, however, and today's reality is that XR content tends to be expensive. In his book *Experience on Demand*, Jeremy Bailenson (Director of Stanford's Virtual Human Interaction Lab) made a number of observations about these issues, including the following:

- When referring to the excellent VR Field Trips that Professor Chris Dede (Professor at Harvard's Graduate School of Education) had created for his students, Bailenson noted that "One thing that became clear through our collaborations is how much time, effort, and money went into building his VR Field Trips. Years of blood, sweat and tears from teams of engineers and programmers, 3D artists, education specialists, story boarders and actors."[12]
- And while, in general, 360° videos can be cheaper to produce than other XR content, Bailenson notes that "The production costs for the 360° videos that are being produced by news organization like the New York Times can exceed hundreds of thousands of dollars for a small set of videos—and their aren't even interactive."

Recent years have seen growing number of media organizations, including New York Times, Harvard Business Review, US Television News Organizations[13] and others taking a growing interest in creating XR content. Unfortunately, very seldom do these organizations report on the costs of these XR projects, most of which are experimental, and high costs are likely as they are all climbing a pretty steep learning curve. And XR-Edu content could no doubt be made at much lower cost, and companies like Thinglink (one of the Finnish 360° video companies, now located in Palo Alto, CA), no doubt are way up on the learning curve and thus are producing 360° video content at much more reasonable prices.

4.4.3 Content Tool Landscape

However impressive technology progress is "on the supply side" of the XR industry (including on HMDs, especially), great content is what will enable the types of experiences that will drive the "demand side of the industry." And even if we are not looking for a "killer app" for XR-Edu, the growth of the industry will suffer without strong content. This is as true for the biggest sector of the XR industry, namely games and entertainment, as it is for Edu. The good news for the future is that the last few years have seen a growing number of tools and technologies that make it easier, and cheaper, to create higher quality content (by the studio sector as well as in the case of user-generated content), and when easier-to-use (and more affordable) tools also result in growing "democratization" of content development, the future for XR becomes brighter.

More and better content can be seen as a result of a combination of developments in what Jonathan Ching of Virtual Reality Pop sees as the "Content Value Chain" with (1) capture hardware (such as GoPro, Nokia OZO, Lytro), (2) content creation studios (many of these all over the world, including game-focused studios now moving also into XR in the Nordics), and (3) software creating software (including Kolar, Video Stitch, Kolor and others) funneling XR content via (4) middleware (consisting primarily of Unity, Unreal and Crytek) to the (5) consumption apps (Jaunt, NextVR, and others) and (6) consumer

[12] Page 234

[13] ABC News, for instance, reported that its AR project to create better visuals for the US midterm elections, "the graphics are made up of about 36,000 lines of code with more than 1,000 markers embedded on set to track 3D content, such as a model of the US Capitol and the seats in the respective chambers and the latest results. Anchors will be able to activate AR content live during broadcast via touch screen displays." No cost was reported, but it likely was into the many hundreds of thousands of dollars. https://bit.ly/2BnEte9

hardware (headsets of major tech companies, etc) needed for consumers (or enterprise users) can have the desired experiences.

Content creating studios in the second leg of this "content value chain" take advantage of improving hardware for capturing 360° video, for example (enabled by improving cameras at both the high end, costing many thousands of dollars, to cheaper GoPro cameras). Growing number of SDKs (software development kits)—including some from Apple (ARKit) and Google (ARCore) that have gained considerable traction over the last few years—are now helping facilitate and democratize AR content creation.

Currently, the bulk of XR content is created with tools and technologies of three major companies: Unity Technologies (founded in Copenhagen, but HQ now based in San Francisco), followed by Unreal and CryEngine. These companies are dominant players in the online and video game development industry, and their tools and technologies dominate XR content tools today. But many other players are also active in building 3D modeling tools that can find use in XR applications and have strength in particular sectors. Autodesk, for instance, is strong in industrial design tools for the design and architecture, engineering and construction industry (with its AudoCAD and 3Ds Max software platforms, for instance). Another player in a similar space is Dassault Systems, with its Solidworks tools, all of which can find use in industrial VR applications. Other companies, such as EON Realities, also build excellent tools and platforms that they use in their own projects. But these are also used in education and learning initiatives they are involved in (more on this, describing both EON Realities and VR First initiatives on this front can be found in later sections of this report).

Many smaller companies have emerged in recent years to create software tools, including some that are targeting the education and learning sector. One of these is CoSpaces EDU, which is described as a browser-friendly software tool that allows students "to create and build a virtual reality world as simply as dragging and dropping 3D objects into the VR space. Advanced students can animate characters and other 3D assets using Blockly or Javascript. The resource can be used on a Chromebook, laptop or mobile devices to allow students to easily design and share a VR world."

Figure 5 illustrates just some of the AR content creation tools that have emerged in recent years to target the education industry.

Figure 5

AR Content Creation Tools

Source

Besides a growing number of content tools and technologies, greater awareness of XR and more educational and training opportunities for anyone interested in learning to create XR content is growing steadily and spreading. In the US and other countries, libraries and community centers are taking on new roles. Libraries in the US and other countries are becoming "maker spaces" that increasingly cater to "doing/building things"—either "real" or virtual--and other community and learning centers are offering XR classes This, in combination with a variety of interesting educational developments in both K12 and Higher Education, will likely make XR technologies more accessible as well as interesting as career paths for students.

4.5 Major XR Application Areas: Overview

New applications and use cases of XR are growing steadily as potential users—in various industries/sectors, including educational institutions (K12 and Higher Education)—gain greater awareness and understanding of these technologies as well as interest by both users and developers in "pushing their boundaries" of these technologies. Already, a wide variety of industries and sectors are experimenting and testing XR technologies, and the spreading adoption will likely stimulate growing interest and more experimentation in other sectors. While most of this will happen outside schools and universities, these developments will likely also generate growing interest among students, teachers and researchers in academia—and the result will be greater willingness to innovate and experiment in how education and teaching can be changed.

As noted earlier, most of the attention around XR has focused on entertainment and gaming, as many see XR as the next-generation game environment/platform, although some (including in Facebook) also

see potential mass adoption of XR as a more broadly focused social media platform. While analysts continue to speculate about where mass adoption of XR will likely take place, and what will drive it, a steady stream of interesting examples of use of XR across a number of industries and sectors continue. Here is a small sample of interesting applications that illustrate where interest is growing and what may be indicative of what we will see in various industries and sectors in the future:

- **Health care and medicine, including medical education and training**. This is an area where XR seems to have strong potential, and a growing number of medical centers and hospitals around the world are now testing out XR for treating phobias (see Box C below), as well as for planning and preparation of medical procedures, for example. Institutions like the University Hospital at the University of Oslo has used Microsoft's Hololens for planning of surgery. Illustrating the growing awareness and potential of VR in health care is the fact that the popular US business magazine Forbes recently ranked VR as **"**the No. 1 example of Customer Experience Innovation in Healthcare." (We may soon also see growing cases of fitness and health maintenance—also referred to as "self-care entertainment"—similar to this case reported recently in the newsletter *Inside VR & AR*: "A man once known for dropping 50 pounds through VR exercise is now working to bring that experience to others by co-founding Orpheus Self-Care Entertainment."
- **Safety and emergency training**. These kinds of applications were popular in the days of Second Life, and some of the companies that are now active in XR were building and running safety and emergency training operations where users, via their avatars, could get a first-hand experience of what these situations were like and learn how to react to avoid harm. As we now see growing use of "digital twins" of a growing variety of machines and facilities (including power plants, etc), these 3D models can then be used in immersive environments where workers can learn how to operate them—or train how to deal with emergency situation in nuclear power plants and other facilities where virtual training has strong appeal—and can be very cost-effective.
- **Military applications**. The US Defense Department (US DoD) is the world's largest training organization and is known to be exploring, testing and using leading-edge technologies for training and other applications. And its Defense Advanced Research Agency (DARPA) funds early development of new technologies. US DoD, and other countries defense departments, are currently testing various applications of XR, and one report (February 2018) by Insight Partners, forecasts the global XR defense market to reach about $1.8 Billion in 2025. According to one company serving this market, "Where today's high-end simulators rely on large and expensive display environments using domes and collimated displays, next generation training systems will benefit from emerging XR technologies that enable solutions that are orders of magnitude less expensive, provide higher fidelity, and offer a smaller footprint supporting training at the point of need." Supporting this emerging trend, a September, 2018 report by the US media and analyst company Bloomberg, noted that Magic Leap is bidding on a contract with the U.S. Army to build AR goggles for soldiers to use on combat missions. The article also notes that Microsoft has expressed interest in providing augmented reality equipment for the battlefield and that "the military could purchase more than 100,000 augmented reality headsets as part of a more than $500 million program that is intended to "increase lethality by enhancing the ability to detect, decide and engage before the enemy."
- **Manufacturing operations**. A recent report examined the following manufacturing uses that are now emerging for XR (and the 2018 Augmented World Expo conference in Santa Clara, Silicon Valley included a number of presentations of use cases from manufacturing):
    - *Design and Visualization*. Both Autodesk and Dassault, referred to earlier, are especially active on this front, both in automotive as well as in architecture, engineering and construction industry—and AEC Hackathons like the one that took place in the SF Bay Area

in Feb 2019, typically include a number of XR projects. Use of XR in urban planning, including smart city developments, is also likely to become increasingly common.

  - *AR on assembly line or in equipment maintenance*. Boeing, Airbus and other aircraft and other types of manufacturing companies see AR assisting with complex assembly as "already a tried-and-tested AR application." Other, like Mitsubishi have "been developing maintenance-support technology using augmented reality based on a 3D model that enables users to confirm the order of inspection on an AR display and then enter inspection results with their voice." Thyssenkrupp's very large service engineer corps has been benefited from hands-free remote holographic guidance, and similar use cases can be found in numerous other manufacturing companies.
  - *Training and Skill Development*. One of the most well-known benefits of use of XR is to provide a "safe environment" to learn new skills and procedures without endangering people or equipment, or of causing damage to expensive machinery and equipment. Companies like Upknowledge in Finland—which has long been active in working with a range of large Finnish companies by using XR technology for training and skill development—will likely see growing demand for these kinds of services as demand for more advanced workforce skills and competencies keep rising as companies utilize increasingly complex machines and tools.

- **Education and Learning**. Later in this report, we will see what Nordic/Baltic organizations are doing on this front, but in the US and European countries, growing number of projects/pilots have been testing XR in various learning environments. Here are just a few examples to illustrate recent or current activity on this front:
  - *VR Eduthon in Germany*. This has been a collaborative initiative between Samsung Electronics Germany (using Gear VR) and Cornelsen, a schoolbook publisher in Berlin, focusing on biology education and providing students between 7th and 9th grades with practical and interesting learning materials. In some ways, this may be similar to what Labster and Google have been doing for university students (see discussion in section 5.1.2), leveraging Labster's 3D models and platforms.
  - *Foundry10 pilots in US*. As noted in Box F, this Seattle-based research company has been involved in numerous XR pilot studies involving well over 1,000 students and numerous schools, examining XR experiences of both students and teachers with these emerging technologies.
  - *ClassVR in Scottish schools*. In spring of 2018, the East Renfrewshire Council reportedly gave 30 schools ClassVR headsets—"full standalone headset specifically tailored to take students on virtual field trips and history lessons that can be guided by teachers"—and investing £250,000 to provide 900 ClassVR headsets to every school in its area. It is yet unclear whether any academic researchers are, or will be, involved in assessing this use of VR in Scottish schools, but one would hope that would be the case, so that whatever lessons and insights are gained can be shared with other schools in Scotland and elsewhere.

Box C

XR in Health Care and Medicine

Health and medical use cases of XR go back many years and numerous academic and industry VR labs have done projects to test out such applications, often in collaborative projects. As noted in his book *Experience on Demand*, Jeremy Bailenson, the head of the Stanford University's Virtual Human

Interaction Lab (founded in 2003) has done numerous therapeutic VR projects, dealing with fear of heights, certain insects and other things. More recently, Oxford VR, a spinout of the University of Oxford, developed a program to deal with similar phobias. Anatomy training is also a common target application for both AR and VR, used in many medical facilities around the world, including many connected to leading universities. Stanford (see bullet on TriPoint Lab below), Temple University and the Lewis Katz School of Medicine, and Fraunhofer Institute for Biomedical Engineering in partnership with Promotion Software and Saarland University, have been among those active on this front.

Relatively larger industry players (compared to small nice studios and startups) like EON Reality (more on their operations in Norway later in the report) have long been serving medical clients with VR solutions (platform and content). EON's clients include Schools of Medicine (like Yale School of Medicine, Stritch School of Medicine at Loyola University, College of Medicine Phoenix, and others) as well as large pharmaceuticals and other health sector organizations.

Kaiser Permanente—a large US integrated managed care organization based in California—has worked with Oculus and Children's Hospital Los Angles to test a VR training program over the last year that enables critical events such as pediatric resuscitation training more frequently than they otherwise could. According to the report in VRScout, "the program will soon roll out to John Hopkins University Health System; Kaiser Permanente Health Network, Southern California; Medical University of Vienna; New York University / Langone Medical Center; Stanford University / Lucile Packard Children's Hospital; University of Bern; University of Washington, and Yale New Haven Health."

Growing number of smaller players and startups are also doing interesting work in the XR front of health and medical applications, including:

- **TriPoint Lab**—This startup is leveraging great relationships and world-class expertise of medical researchers, including in AR, VR and simulations technology, as well as high quality content for curriculum, at Stanford Medical Center, where the founder of TriPoint Lab, Matt Hasel, has worked for many years. Interestingly, the company is also looking to connect its platform to adaptive learning technology to provide a complete "Next-Generation Educational Technology" system and platform.
- **Arch Virtual**—The founder of this startup, Jon Brouchoud, was one of the most active and innovative designers on the Second Life platform of Linden Lab about 10 years ago. The company is now building high quality immersive VR environments for a range of clients, including some medical schools for applications in health and medical, as well as for safety training.
- **Medical Realities**—The UK company's platform is used by a number of medical centers in Europe and works with a number of industry partners to create high quality curriculum content. The company also uses the Jaunt XR Platform for cross-platform distribution of immersive content.

4.6 Implications for Nordic/Baltic XR-Edu

Sections 4.1-4.5 provided a "brief XR summary tour" of selected issues and developments that shape and influence the overall global XR environment in which the Nordic XR technology and service providers and users of these products and service, including Edu, will be affected by in various ways. Continued globalization of the XR industry will likely continue, and likely even accelerate, especially as Asian, and

especially Chinese companies, continue to push into overseas markets. XR developers and consumers in the small Nordic/Baltic countries (totaling a population of only 33 million) will no doubt look to participate in and benefit from the growing XR industry. What role Nordic/Baltic XR companies may have in the global XR industry is far beyond the scope of this report. A question much more pertinent to this report is to what extent, and how, the Nordic/Baltic education, learning and training—referred collectively with the term Edu in this report---will be able to take advantage of emerging XR technologies.

Many questions about XR still remain about *where* (i.e. which areas/activities/processes of Edu) and *how* XR technologies can best find use in Edu, in order to have the greatest impact on learning outcomes, and benefit students as well as teachers and professors. Answers to these questions will slowly emerge as more and more pilot studies are undertaken and carefully assessed by researchers. The results—especially when combined with similar studies and findings in other parts of the world, by researchers like those of Foundry10 (See Box F)—can play an important role in guiding policymakers, schools administrators and teachers in the classrooms. Despite a growing amount of activity and innovative applications of XR, as illustrated in earlier sections of this report, much more work needs to be done before we are likely to see significant adoption of XR technologies in Edu and also have confidence in decisions made in where and how to deploy XR technologies.

Some of the implications from the review of global XR issues and developments for Nordic/Baltic XR-Edu are that the following action steps should be considered:

- *Strengthen XR-Edu "business intelligence*." Regional and country-based XR researchers need to build an intelligence system that collects relevant information of projects and XR pilot studies around the world. This information should be used together with information and data from regional and local pilot studies, to help build deployment guides for Nordic/Baltic policymakers, school administrators and teachers,
- *Create XR-Edu Forums*. These forums will be opportunities to not only share and discuss the results of the global XR-Edu intelligence gathering, but also for local and regional Edu practitioners to discuss and debate what the collected intelligence means for their own projects and XR deployment plans. When students, teachers or researchers attend XR conferences in other parts of the world, trip reports should ideally be shared and debrief be given as a way to spread new insights gained.
- *Collaborate and join forces*. Identify interesting schools, teachers and researchers in other parts of the Nordic/Baltic region, but also beyond the region, that can be potentially useful partners in planned projects that either explore new XR application areas or other issues around XR-Edu. How can you create win-win partnerships where all partners benefit? What can you contribute and what can you gain?

5.0 Nordic/Baltic XR-Edu: Current Landscape and Selected Developments

As noted above, the emerging XR industry, especially when it comes to Edu, is in its very early phase of development, and can be seen as a subsector of the overall "edtech sector" that has gained growing recognition and support in recent years in the Nordics/Baltics. And XR-Edu can also be seen as a subsector of the general XR sector/industry that is still very game and entertainment-focused.

Each of the Nordic and Baltic countries now have a increasingly vibrant edtech sector and a growing range of ongoing edtech activities, and a number of institutions are helping build and support the countries' edtech ecosystems. These developments, including the strengthening of N8 (putting the 5

Nordic and the 3 Baltic countries under an "Nordic 8" umbrella organization of edtech founders), illustrate how to build a dynamic Nordic/Baltic XR-Edu sector, and ideally connect it to the overall Nordic/Baltic edtech community. And as new edtech projects are launched—such as Inno-Oppiva (Co-development of Educational Technology) in Finland, which connects academic researchers to edtech startups in order to ensure that edtech products that solve real and high priority needs are created—similar efforts can also focus on emerging XR-Edu opportunities.

5.1 Denmark

While Denmark has been among the early adopters of digital tools and technologies in schools, so far few projects seem to have yet taken place to test XR in K12 schools (primary and secondary education). As will be discussed in the country sections of Norway and Finland, these countries have had some pilot projects to experiment and test VR at the K12 level, but across the whole region, much of the attention on XR seems to be in higher education[14], and this certainly seems to be the case in Denmark.

Denmark currently has an ambitious program to not only test out, and research, the potential role and efficacy of VR in education of any of the Nordic & Baltic countries, due to ministerial-level support and funding for use of immersive technology. This ministry support, and the role of a leading edtech company (not just in the Nordics but at the global level), Labster, are key elements in Denmark's XR activities. But as will also be discussed below, EON Reality—which has been most active in Norway—has recently also expanded its operations to Denmark, adding a potentially important element in Denmark's XR-Edu ecosystem, with most activity at the university rather than school level.

This report has referred a number of times to how growing use of so-called "digital twins" in industry (and likely in academia as well) will open up interesting, new applications for XR technology. Denmark's MCI Digital Twin Lab—in the Mads Clausen Institute, at SDU Technology Entrepreneurship and Innovation, University of Southern Denmark—envisions similar future developments. It sees itself as "a new digital workspace, where students, researchers and practitioners can utilize new technologies in Virtual Reality (VR) and Augmented Reality (AR). At MCI we are interested in investigating how the role of these new technologies can be utilized as an interface to an increasingly digitalized world."

5.1.1 Roskilde University and Ministry of Education Project Support

Roskilde University (RUC) is one of 8 universities in Denmark (located on the Sjaelland island, near Copenhagen and the southern Sweden city of Malmo), and its student population of only around 8,000 makes it only the 7th largest in the country (Aarhus University is the largest, with 44,500 students, followed by University of Copenhagen, with 38,615 students). Yet, despite it relatively small size, RUC was the beneficiary of a DKK 20 million (about USD 3.1 million) grant by the Ministry of Higher Education and Science for "virtual learning technologies" announced in January 2018. According to the press release,

[14] This sector in reality includes the following types of institutions, but I will focus my attention on only the first category: Universities; Institutions in architecture and art (where AR/VR could find considerable appeal); University colleges (many of which over time become full-blown universities); Business academies; and Maritime educational institutions. https://en.wikipedia.org/wiki/List_of_universities_and_colleges_in_Denmark

the new project would "develop virtual learning technologies and map the best way to use the new technologies for teaching in the future." The initial press release did not specifically use the terms of AR or VR, but subsequent developments make it clear that XR are key parts of that the project will explore for education, teaching and learning.

To understand the thinking of those involved in designing the proposal to the Ministry, the quotes in the bullets below (from the statements in the press release by Hanne Leth Andersen, who is the rector at Roskilde University and a professor of higher education) are interesting and show a bit about the vision that RUC, the Ministry and others (perhaps including Labster; see below) have about "virtual technologies" and their potential role in Denmark's "next-generation learning/teaching systems":

- "Denmark can become a front-runner in the field of teaching technologies, because we have a particular opportunity to combine technology with educational, social and cultural knowledge."
- "The strength of anchoring such an effort at RUC is that we are strong in the area of interdisciplinary approaches."
- "This is about preparing students for a world where virtual reality is already an integral part of everyday life, across academic disciplines."
- "Virtual learning technologies provide special opportunities within the areas of natural and health sciences [strong alignment with focus areas of Labster; see below], but we will also prioritize having other types of learning forums. The project is a unique opportunity, which also goes hand in glove with the expansion of our digital technology development here at RUC."

While RUC will lead the project, the press release also notes that "The project is intended to act as a platform for establishing a broader collaboration within virtual learning. RUC will invite other educational institutions, development environments and companies to participate in a broad collaboration". A subsequent update on the project and its future activities was made in November, 2018, noting that RUC is in the process of creating a new Center for Virtual Learning Technologies (as one part of the project)—which plans to research and identify how learners benefit and make recommendations about how learners can best benefit from using VR—and the update now makes specific reference to VR.

Other interesting aspects of the RUC VR project and questions it raises include:

- The virtual technology initiative makes reference to collaboration with other Danish universities, most of which are much larger in size than RUC. How many of the other universities already have, or are planning to set up XR Labs, and do joint and collaborative research around XR use in higher education and learning in Denmark? And will these activities include using XR in their teaching and learning activities as part of current curriculum or new curricula that is being planned?
- RUC has already received Google Daydream headsets, part of a strategic collaboration agreement which Labster has concluded with Google (see below), but does this mean that future VR in education research will be limited to use of a stand-alone, mid-level VR headset (delivered by Lenovo), requiring use of Daydream-compatible smart phones?
- The November 2018 press release makes reference to RUC as the "first university in Europe to integrate VR-simulations-based learning into a science education program." So, it seems clear that RUC is ready to move VR beyond the lab and into the classroom as part of its current degree program." But these efforts and activities may still be part of the research undertaken in RUC's new Center for Virtual Learning Technologies.
- Besides the likely collaboration with other Danish universities (which the January 2018 announcement made explicit reference to), will RUC also be open to, and perhaps even seek,

research collaboration from other academic institutions in the Nordics, Baltics and perhaps in Europe and the US more generally?

5.1.2 Labster—Leading Provider of Virtual Platform for Science Education

Labster is one of the most successful Nordic edtech companies, founded in 2012, seeing itself as "dedicated to developing fully interactive advanced lab simulations that are designed to stimulate students' natural curiosity and highlight the connection between science and the real world." The company has received $10 million in funding (investor capital, not including grants) so far, but Labster reports total funding (grants and investment funding) at over $20 million. And the company has been very successful not only in finding customers, especially among leading higher education institutions around the world, but has also built strong partnerships for marketing and research purposes, including with companies like publishing/education companies such as Pearson and Springer.

An announcement (written by Mikkel Marfelt, Director of Research Partnerships at Labster) in April, 2016, pointed to the kinds of developments we have seen from Labster during 2018—and perhaps setting the stage and creating the foundation for the RUC grant described above. The Labster press release noted that Innovation Fund of Denmark would invest DKK 24 million (about USD 4 mill at the time) over the next four years "to leverage Labster and its strong global alliance of experts [via its university partners], and Labster will lead the project and develop and refine a virtual reality learning platform". The note identified its strategic partners to include MIT, Stanford, UC Berkeley, Copenhagen University, Southern University of Denmark, DTU, Center of Biosustainability, and the US biotech company Biogen.

Three of Labster's recent partnerships which show the company's strategic vision for use of VR (and perhaps AR) in the future are those formed with Google, Springer and Pearson:

- **Google.** The Labster-Google VR strategic partnership was announced at the big Google IO 2018 event in May, and is significant in many ways. This is in part because Google not only has had considerable success with learning technology/platforms (especially via its Chromebooks, which has displaced Apple's iPads as the platform of choice in thousands of US schools), but the company now also has VR platform, including its mid-end Google Daydream (with Android and other smart phones). Teaming up with a tech giant like Google may help Labster put low-cost VR learning platforms into schools and universities around the world. It may also help raise the funding to market and distribute these VR solutions—but some experts question Google's commitment[15] to VR and also note that "the window is starting to close [on coming up with a strong competitor to Oculus Go and Oculus Quest], and it's becoming increasingly clear that phone-powered VR headsets like the Daydream View have no future."[16]

  Labster's academic alliances are an important and impressive part of its longer term strategy of developing its VR platform and simulations with leading university players (in Denmark, other parts of Europe as well as the US), including Arizona State University (ASU), one of the most innovative universities in terms of online learning in the US. Labster VR reports that it has worked with faculty at ASU to "validate the content of the labs and ensure that all learning objectives were

[15] Which in part comes from the non-presence of Daydream at Google's hardware event.
[16] See "ProBeat: Hey Google, was Daydream just a dream?"

met, so that ASU was able to provide full course credit to students using Labster VR simulations as part of their course. In the fall of 2018, ASU reported it would launch its first fully online biology degree using Labster VR. This degree would consist of 30 Labster VR simulations in cellular and molecular biology, ecology and animal physiology. Soon students at Roskilde University in Denmark, the University of Texas, San Antonio, McMaster University in Canada, and Roger Williams University, Rhode Island will be using Labster VR as well. Several of these universities will be engaging in research around the use of VR in higher education."

- **Springer.** Following up on its May 2018 deal making with Google, in November, 2018, Labster concluded a partnership with the German publisher and media company to combine Labster's lab simulations—and also leveraging its VR platform and Google collaboration, perhaps?—and Springer's considerable science resources (mostly in books and booklet form). The two companies have created four booklets for biology in higher education and will align the concepts of the booklets with Labster simulations which "the students can use to solidify and test their knowledge and practice the techniques that they have read about with a hands-on lab experience. This is made possible by multiple choice questions, 3D animations and cutting-edge lab equipment that is available to the student through the virtual labs."[17]
- **Pearson.** This strategic partnership between Pearson—"the world's learning company"—and Labster, could provide Labster strong outreach in the US and potentially give the company a significant market share of US high schools in coming years. The partnership comes in tandem with the release of the newest edition of Pearson's Miller & Levine Biology textbook, and the simulations are set to be rolled out to across the U.S. However, it is uncertain to what extent, and how quickly, the schools, teachers and students will be migrating to using VR-based biology simulations.

5.1.3 EON Reality in Denmark

EON Reality is a large US technology company that has provided XR technology since 1999, initially from its HQ in Irvine California, but today with Interactive Digital Centers, VR Innovation Academies, and offices all over the world, and bringing XR innovation to numerous locations in the Americas, Europe, Africa & the Middle East, and Asia & Australia. As will be seen in section 5.3 on Norway, this is where EON Reality has built a strong base for its European operations, but in 2018 it also expanded its Nordic operations into Viborg, Denmark.

As in Norway, where EON is part of a private-public partnership with numerous partners, in Viborg (a city in central Jutland, half way between Aalborg in the north and Aarhus a bit further south, on the coast) EON teamed up with the municipality of Viborg and VIA University College, a second tier university in Denmark—with a number of locations throughout Jutland—but with considerably more students than RUC: 20,000 at VIA versus 8,000 at RUC. The Viborg establishment by EON has a number of parallels to its Hamar operation in Norway, as both have significant gaming and animation activity, and Viborg's Animation Workshop has built up new media skills and competencies that are attractive to EON. Also, as in the Hamar, EON Reality has worked with a local academic institution, in this case VIA University College. VIA has established a new certificate degree for engineering and animation students so they can

[17] https://blog.labster.com/springer-labster-partnership

specialize and get a VR and AR certificate—and the first cohort of students in this program started in February 2018.

5.2 Finland

Finland does not (yet) seem to have the kind of high-level projects in Higher Education (i.e. initiatives with Ministry funding and support) in XR-Edu that Denmark has via its RUC-led initiative discussed earlier. But, as will be seen in section 5.2.2 below, the Finnish National Board of Education and the Ministry of Education and Culture have funded two XR projects to examine the use of these technologies in schools[18]. Finland also has a very impressive and extensive XR ecosystem, and it has also done a good job in mapping out its XR ecosystem, which is quite impressive in size and scope. This mapping of the emerging XR industry was done in these two reports:

- **VR/AR Industry of Finland, 2017**. This 103-page report, written by three members of "Team FIVR" (i.e. the Finnish Virtual Reality Association), with financial support by Tekes (the Finnish Funding Agency for Research), provided "an overview of the Finnish XR ecosystem in 2017, with information of current business, research and education initiatives and network groups of the VR, AR and MR technology field." A review of the report will provide a good overview of the overall Finnish XR ecosystem, but here are a few insights with respect to Edu: (1) Finland has a number of players that are active in 360° video (and one of the early players in this area, Thinglink, is referred to below, in the context of the VISIOT project)—a form of VR that is easier and cheaper to use than other forms of VR and thus has appeal in education; (2) Among the many VR players profiled in the report, 10 of them (including Ade Oy, Avains, Betterday Innovation Oy, and Eligo.Studio Oy) claim to be focused (at least in part) on training; (3) Five companies (Finpeda Oy, Leonidas Oy, Lyfta, ThinkLink, and Visumo Oy) are targeting the education sector specifically; (4) Finland has a number of VR support organizations, including Tekes, FIVR (Finnish Virtual Reality Organziation), Nordic VR Startups, VR Finland, as well VRARA (a Finnish chapter of the VR/AR Association).

Box D

Vizor: Finnish XR-Edu Innovator

Since XR is an emergent and dynamic sector, the list of companies listed in the XR Industry of Finland, 2017 report will inevitably miss new companies, some of which are already playing interesting roles in the XR-Edu segment of the XR industry[19].

One of these companies that was not mentioned in the VR/AR Industry of Finland, 2017 is Vizor, a company that began its journey with Patches, a "full-feature web-based 3D editing and prototyping tool with visual scripting." The company enables users to build their own VR experiences with the help of just

[18] In early 2017, The Ministry of Education and Culture also funded the project "Experiencing the Equations" for developing XR platforms for education, and this project helped contribute to the launch of company Demola that later evolved into Meini, a startup that went through xEDU, Finland's edtech accelerator.

[19] xEDU—the first Nordic edtech accelerator (in Helsinki)—which has now graduated 47 companies (from 8 countries) since its start, noted in its recent annual report (Impact Report 2017-2018) that six companies focused on XR have gone through its acceleration program: 3D Bear, SimLab IT, iSci, Meini, Eduality, and Lyfta

a browser. According to founder Antti Jäderholm, Vizor is used by schools all around the world to introduce students to VR as well as by marketing agencies and media houses. Their virtual reality experience is compatible with most commercial VR headsets.

- **Mixed Reality Report 2017**. This report was done for, and funded by, Business Finland (a fusion in 2018 of Tekes and Finpro, an export-promotion agency for Finland) and done in cooperation by Neogames Finland (a member-based, non-profit, gaming industry association), and the Finnish Virtual Reality Association. The report complements the XR Industry of Finland report, which mapped out the players in the ecosystem, while the Mixed Reality Report is more focused on devices and the marketplace as well as investment funding available. The report authors state the following as the main goal of the report: "Provide a somewhat coherent view of XR possibilities open to game developers at the moment, and describe some of the possibilities in the field." Game developers, is the main audience the report is aimed at, but of course, many of the game development studios (in Finland and elsewhere) have also moved into serving Edu markets, especially as game-based learning has gained popularity as a way to gain learning engagement.

5.2.1 State of Finnish XR Industry and Implications for XR-Edu

To my knowledge, no survey has been done of all higher education institutions in Finland about how many have XR labs and whether labs that are in operation are focused only on research or also supporting deployment of XR for teaching or learning purposes. And the two reports I described above, and will discuss further below, don't report what is happening in academic XR labs. But my discussions with people in Finland who are knowledgeable about the state of XR in Finland, reveal at least these three universities are among those that have active XR labs—and are working, directly or indirectly in XR-Edu:

- **University of Helsinki (UoH)**. The MR [Mixed Reality] Studio-Hub at UoH may well be one of the largest labs in terms of focusing on Edu issues. But while training/education is one of the focus areas, they also do a lot, perhaps most, of their work relating to (business) sales and service issues, and how MR technologies can be used by industries (such as forestry, for instance)—as a "tool for business"—that are very important to Finland. The Studio/Hub has a staff of close to 20, and serves a variety of roles, including demonstrating MR technology use, now and in the future, to both students and to their larger community. In late 2017, the Hub also created three new positions as "digitutors" for forestry, medicine and pedagogy, to work with students and others focusing on these three areas, both in industry and education.
- **The University of Oulu (UoO) and Oulu University of Applied Science (OUAS)**. These two universities—which may perhaps be merged as happened recently in Tampere (see below)—have a number of different labs that work with a range of XR and related technologies. In addition to running one of the earliest CAVE[20] environments in Finland, UoO has the Center for Ubiquitous

[20] Cave automatic virtual environment (commonly refered to as CAVE) is an immersive virtual reality environment where projectors are directed to between three and six of the walls of a room-sized cube. In some universities, such as NTNU in Norway, large and well-resources companies—such as Statoil (now Equinor) in Norway—helped fund both the CAVE and the research of interest to the companies. [Get this confirmed—from Ekaterina or others]

Computing (UBICOMP), that has considerable XR technology expertise. Despite having Steven LaValle (co-founder of Oculus VR) as one of the leaders of the center, it appears that relatively little XR work is done, at least with any Edu focus, such as exists in UoH's MR-Hub.

- **Tampere University (TU) and Tampere University of Applied Science (TUoAS)**[21]. These two institutions have a number of XR-related activities and organizations, including Center for Immersive Visual Technologies (CIVIT, which has been funded jointly by Academy of Finland and Tampere University of Technology) and a Gamification Group (also known as AFAIK). While CIVIT's activities may result, either directly or indirectly, in conceptual or practical outcomes with Edu applications, most of its work is to "develop new scientific and industrial applications where advanced visualization is a must." AFAIK, on the other hand has a number of focus areas that could have more immediate and direct value to XR-Edu. The group is interested in how AR can boost collaboration, how to create AR/360° video applications and design, and to study the effect of XR on empathy, all of which could yield new insights and benefits for use of XR-Edu. And since gamification has gained growing role as a way to achieve greater student engagement in learning, and since XR can have potentially significant impact on learner engagement, AFAIK work with XR could have significant role in Edu.

Other academic/university research labs and private companies or research labs are also likely testing or have already deployed XR in their operations—but most of these operations and activities may not have much Edu focus. However, exceptions are likely to exist, and it is clear that a number of the projects of VTT[22], for instance. VTT has long and extensive experience in many aspects of XR, evident from their various projects in virtual technologies[23]. And one project, in particular, has clear and direct relevance for Edu: Mixed Reality Applications for Culture and Learning Experiences (MIRACLE). The box below provides a brief description and raises some issues and questions around this project.

Box E

VTT's MIRACLE project: Project Summary and Implications

- **Brief project description**. *The Mixed Reality Applications for Culture and Learning Experiences* (MIRACLE) was a research project by University of Turku, VTT Technical Research Centre of Finland, University of Tampere, and University of Helsinki. The project ran for two years in 2015-2016, with the main funding coming from Tekes, alongside a number of project partners from public organizations to private enterprises
- **Project Ojectives**. These included: (1) Find ways to create attractive visitor attractions and experiences for customers of museums and other culture-related attractions; (2) Create attractive mixed reality applications for cultural travel and out-of-classroom learning; and (3) leverage capabilities of multi-disciplinary teams and in cooperation with local business.

[21] Tampere University of Technology (TUT) recently merged with University of Tampere (UT) to create a new Tampere University (UT), and this, together with TUoAS, now "constitute Finland's most diverse university community, with over 30,000 students and 5,000 employees."

[22] "VTT Technical Research Centre of Finland Ltd is a state owned and controlled non-profit limited liability company" (https://en.wikipedia.org/wiki/VTT_Technical_Research_Centre_of_Finland) similar to, but on a much smaller scale, Fraunhofer in Germany.

[23] See http://virtual.vtt.fi/virtual/proj2/multimedia/ and hyperlinked documents

- **Project Outcome**. Leveraged knowledge from project demonstrator applications into knowledge in the form of (1) toolkit (with elements for developing applications), and (2) a handbook that "define the recipe efficiently and economically developing attractive applications and running businesses around them."
- **Project Impact and Implications**: According to Pekka Ollikainen, Senior Adviser, Digitalization at Tekes, the results of MIRACLE is being used in many museums and exhibitions in Finland. As is usually the case with Tekes projects, MIRACLE has also has impact on other Tekes projects, including EIT Digital (such as Smart Digital, by Nokia & mFabrik). Since it has only been two years since the project was completed, the full economic and social impact may not be clear for some years. Hopefully, the toolkits developed in MIRACLE will find use and result in new applications and new attractions for museums and other culture-related applications (and, as Ollikainen notes, such impact has already been seen at some level). What is not clear (yet), is whether any important insights and lessons learned came out of the project that could help guide future XR-Edu projects in Finland or elsewhere.

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5.2.2 Projects Assessing Opportunities for XR in Finnish Schools

As noted earlier in this section on Finland, I have so far found only two significant projects on XR in schools in Finland, and below I provide a relatively brief summary of these projects that may have value for others in the Nordics/Baltics either doing or considering similar (K12)-type projects to examine the potential role and impact of XR in schools. As will be seen below, the first of these projects also had an interesting dimension, as it became a (small) component of a larger, US/Canadian, multiyear project that has examined various aspects of XR in schools (and Box F describes the Seattle-based education research organization, Foundry10, which designed and managed this study).

5.2.2.1 FinEduVR

This project—led by three school teachers and principals[24] with strong interest in technology in education, who were intrigued by the potential role of VR in future education in Finland, and having seen the arrival of more sophisticated technology (esp headsets)—gained funding (Euro 150,000) from the National Board of Education[25] for a two year project (2015-2017). Four high schools from Murame, Jyväskylä, and Kuopio cities participated in the project, and the project ended up with a total of 10 teachers and around 25 students from these schools.

[24] Timo Ilomäki (Teacher and Coordinator), Aki Puustinen (Coordinator and Principal), and Jukka Sormunen (Company developer and School Principal)

[25] The Finnish National Board of Education (FNBE) is a national development agency, responsible for the development of pre-primary, basic, general upper secondary, vocational upper secondary and adult education. FNBE is subordinate to the Ministry of Education and Culture. The Ministry has funded a number of projects that have helped build XR capability in Finland. In some cases, such as the project funding for platform design and innovation, led to the startup firm Demola which in turn led to Meini, an XR startup that participated in xEDU edtech accelerator.

Interestingly, the project was launched at the same time as another, much bigger, project with many of the same goals as the FinEduVR project, was kicked off by Foundry10 out of Seattle (see Box F). The Finnish team traveled to Seattle to discuss their project and ended up aligning the projects and the data from the FinEduVR project were incorporate into the US/Canadian project. The goals set by the FinEduVR team at the beginning of their study included the following:

- Gain insights into what kinds of learning experiences would benefit most from a VR-type learning environment.
- Offer 360-degree video production skills and tools to high school teachers and students.
- Create better understanding of current and future potential of VR and the developers of the technologies of Oculus/Facebook, Sony, Samsung, Google, Valve, and Microsoft to all levels of the Finnish educational system.
- Test the VR possibilities in a number of high school subjects, such as history, geography, biology, sports, arts, etc. as well as in team learning and entrepreneurship studies.
- Test VR as a potential tool to use in the marketing activities of schools
- Organize high school level national VR game event, together with students and teachers
- In cooperation with two industrial partners—Samsung Finland and Edutukku (a vendor of educational technology and supplies)—the project wanted to test Samsung Gear VR learning environment.
- Testing of Google Cardboard (with smart phones) in classroom learning activities.

Box F

Foundry10—Technology in Education Research

Foundry10 is a privately-funded Seattle, Washington-based Learning Research company with a passion to "Change the way people think about learning, and to research new ways of learning", and to use research to create value for kids. The company does an array of educational research, not just technology focused research. But within VR, they are studying: empathy, assessment of learning, equity and access, and creativity/design. Currently Foundry10 is running the following programs: (1) VR applied study; (2) VR experimental study; (3) VR for educators; and (3) VR elementary study. The broad ideas they feel impact student learning in VR are creativity, student voice, gender, design, cognition, and transfer of knowledge.

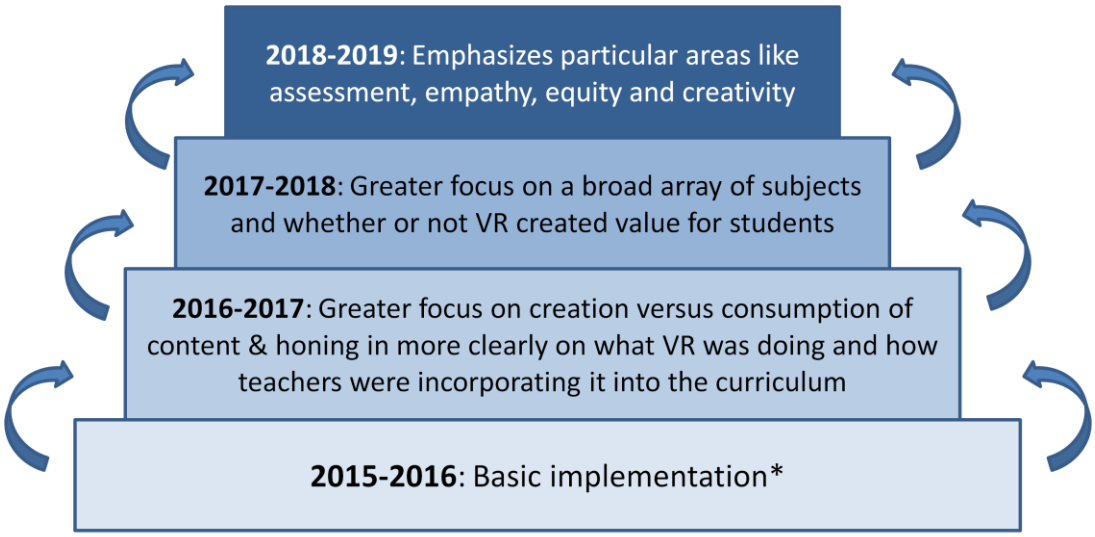
Lisa Castaneda, CEO and Co-Founder, shared with me that each year they have focused on a slightly different area, and leveraging findings and insights gained in one year into following years' research and the questions they examine. Figure 6 below illustrates how the key research questions and focus have evolved over the 2015-2019 period, the first two years of which the FinEduVR project was integrated into the Foundry10 project. The findings of the 2016-2017 study year—which had a total of 1351 students participating across six grade levels—are presented in the report *All-School Aggregated Findings 2016-2017-VR* (available on the Foundry10 website).

Since many, or perhaps most, of the research questions the Foundry10 team are examining would be of interest to those considering, or already involved in XR-Edu projects in the Nordics/Baltics, I thought it would be useful to share the key questions that Foundry10 says their projects tend to examine:

- In what, if any, ways, does VR enhance learning for K-12 students?
- What are barriers that must be overcome in order to successfully implement VR in actual classrooms and applied settings (vs. experimental settings)?
- What roles do perspective taking and empathy play when students engage in VR? How do we actually know if virtual experiences improve perspective taking or empathetic understanding in students?
- How are educators successfully implementing and engaging with VR content in order to meet the course objectives of their subject areas?
- In a classroom environment, what might break the immersive experience for children?
- As educators, how can we best capture the elements that VR, as a medium, offers for learning without falling back into traditional practices that may not best be served by immersive environments?

Figure 6

Foundry10 VR Research Strategy & Issues



Source: Lisa Castaneda, Foundry10 ; Eilif Trondsen, Silicon Vikings

* See Whitepaper on ""10-Things We Learned From Putting VR in Schools"

5.2.2.2 VISIOT

This 2017-2018 project is part of the "New Comprehensive Education" program funded by the Finnish Ministry of Education and Culture. According to the Innokas Network[26] team at the University of Helsinki

[26] The education-focused network has a large number of partners, international as well as Finnish, and works in close collaboration with "schools, kindergartens, public libraries, youth services, universities, municipal and national administration, companies, foundations and other organizations." Innokas Network activities are coordinated by the Faculty of Educational Sciences at the University of Helsinki, in collaboration with 10 area coordinators in Finland.

leading the project, the project supports the "deployment of the new Finnish Core Curriculum by visioning and developing ways to use recently introduced technology: IoT (Internet of Things), AR (Augmented Reality) and VR (Virtual Reality) in practical education contexts in completely new and pedagogically meaningful ways." And the goal of the project is to examine the possibilities offered by IoT and XR technologies for learning key 21st century skills: "Observing everyday technology, creative and critical thinking, problem solving and research skills, and practical skills for living, participating and acting in the digital society. For this, the Innokas Network makes use of its expertise in helping children learn about everyday and future technologies and related phenomena."

Specifically, for XR the project wanted to test and develop XR content for education, and to "find new ways to teach and learn concepts that are normally hard to understand. In addition, this part of the project aims to employ experience-based learning to engage and motivate learners to learn wide-ranging competence." Project findings and insights are currently being written up and will likely be published in coming months, but here are some project elements and findings shared with me by Laura Salo, a project coordinator of a number of the Innokas Network projects, including VISIOT:

- The project included 2 universities, schools in 7 cities around Finland, producing over 60 pedagogical projects, and involving close to 30 teachers and several hundred students from school classes and in events (youngest age 8)—so a considerably larger number of participants than in the FinEduVR project described earlier.
- Teachers involved in the project used the Spring of 2017 for planning, and then they started implementing in the Fall of 2017 and continued during the Spring of 2018 as they decided how to incorporate XR in their own teaching.
- Teachers tested VR technology—including 360° video—in a number of subjects, including history, biology, English language, physical exercise and arts.
- The project funding allowed the purchase of a number of both wired and wireless VR-technologies and gave teachers/schools the opportunity to choose what tech/headsets they wanted. PC-wired technologies mostly involved HTC Vive (and also Oculus Rift). They also used various mobile headsets such as Google cardboard, and teachers noted that the quality of the VR experience became dependent on the quality of phones that students had. Thus, the different technologies used became a major constraint for both teachers and students in testing out VR in the classroom—in part as students had to await their turns to use the headset, and the teacher had to organize a set of different activities etc during this time of testing out VR. Despite the time-constraints, most students found the activities motivating and enjoyable.
- Teachers in Finland are very well trained and used to a high degree of autonomy, and this XR project was therefore not unusual in giving the teachers the freedom to decide not only what technology to buy, but also plan what they wanted to do in terms of finding the best application of the technology and what to do. The challenge remains to find pedagogically relevant programs and content to use in VR.
- 360° video was an element of the project, and the Innokas network concluded an agreement with a US (Palo Alto-based) firm, ThingLink—a firm that was launched in Finland by Ulla Engstrom—that gave teachers access to "premium content" from Thinglink for their school projects for one year.
- Some teachers used VR for collaborative work, and meeting in a 3D environment, among students in different locations and in one case some of the teachers involved a university, University of Jyväskylä, that is active in VR technology.
- The collaborative part of the project that involved the University of Jyväskylä also experimented with 3D art applications, and a preliminary finding of the project was that this kind of application

seemed to work well and to result in active learning and engagement—within an immersive environment—of the students, and enabling and stimulating creativity.

- One of the findings of the project was that, not surprisingly, the quality of the XR equipment can have an important impact on the quality of the learning experience and the quality of the wireless network (when using untethered HMDs), the frame rate, etc. become important factors in the experience—and making it important for teachers to have skilled technical support, and also to gain training to make teachers comfortable in using the technology.
- The project also included one Master student—who did a specific case studies as part of the project—and Box G provides a brief description and summary of one of these case studies.
- Another Master student is currently working on researching the user experience of secondary schools students in VR (2019).

Box G

Virtual field trip project: VISIOT-connected Master Thesis

This project—*Virtual field trip project: Affordances and user experiences of virtual reality technology in actual school settings*—was undertaken by Joakim Laine, for his Master Thesis in the Teacher Education Department in the Faculty of Behavioral Science at the University of Helsinki. And three teachers and 59 students, 5-6th graders, from two different Finnish elementary schools participated in this study, and as a part of the overall VISIOT project. The teachers used HTC Vive headset and Google Earth VR program. A few of the findings from Joakim's study included:

- The teachers encountered technical, spatial and temporal challenges, as it appeared that VR's implementation in education demands different spatial, temporal and pedagogical arrangements than the schools involved in the study were used to
- But the students adapted to the use of VR technology rather quickly and had a very positive emotional experience with it—although the availability of only one headset per class limited access and complicated things a bit. The VR system was mostly used as motivational in addition to contributing to learning.
- While VR could be a valuable part of a student's learning experience, some of the student reaction was likely related to the novelty of the technology and the benefit and impact of VR use over the long run is unclear.
- An important potential benefit for VR in education will be for students to engage in group learning, in an immersive environment, and both interact with 3D objects as well as creating their own content.

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5.3 Norway

Norway does not have a Tekes equivalent organization that has actively supported emergent gaming and XR ecosystem (although the Norwegian Research Council could potentially have played such a role), but the country now has a significant and growing XR ecosystem. According to a recent survey led by the Norwegian chapter of VR/AR Association—headed by Håvard Røste- (Project Manager, Business Region

Hamar & VRINN, Norway[27])—Norway currently has over 60 companies, mostly early-stage companies, with wide-ranging expertise and technical capabilities. The largest number of these companies are located in Oslo, Norway's capital, followed by Trondheim (where Norway's largest technology-focused university, NTNU, is located) and Hamar, and finally in Bergen (a city of similar size to Trondheim, and also with a strong university, but less technology focus). Not surprisingly, given the strong gaming roots of companies in the Hamar region—as is also true in Finland and the other Nordic countries—the focus of many of the Norwegian XR-focused players are on games and entertainment. Many of them are now leveraging their game-expertise into Edu and various industrial applications of XR. Many of these industry applications relate to the maritime industry and well as uses of XR for design, sales and marketing, and advertising in a range of industries, including real estate, energy and engineering. A number of players are focused, at least in part, on 360° video applications, both in commercial applications and in Edu.

5.3.1 Hamar: AR/VR Hub and Emergent Ecosystem

Over a number of years, the Hamar region has built strength around gaming (including the Hamar Game Collective), both through a number of local gaming-related companies, as well as having a university (Now, Inland Norway University of Applied Science, or INN) with a strategic emphasis on audiovisual media. So, when EON Reality "came calling" in the fall of 2016 when looking for a location for its new Norwegian HQ, a number of public and private organizations recognized an important opportunity. This consisted of being able to accelerate the building of a new industry and create new jobs in an emergent and innovative industry of gaming and XR (with a variety of product and service solutions across a number of applications and industries). These players came together in December 2016 to agree on a plan—whose details include those shown in Figure 7 below, that would help create the foundations of what is now a growing gaming-XR ecosystem in the city and municipality of Hamar, and the surrounding areas (of Hedmark county).

It must also be noted that INN—born on January 1, 2017 when Hedmark University of Applied Science and Lillehammer University College merged—was gaining strength in a number of areas and it now has a number of research centers and research training (for PhD studies). The university operates on 6 campuses in south-eastern Norway, and has approximately 13,000 students. The university has strategically prioritized the following two research areas: (1) Applied Ecology, and (2) Audiovisual Media (where gaming and XR programs sit). In the area of education and learning specifically, INN has the Partnership for Education and Research about Responsible Living, and the Center for Studies of Educational Practice (SePU). SePU researchers have already been involved in some initial research around use of VR in schools (specifically in learning mathematics, which the Hamar-based startup, VR Education, is focused on—see Box I). Its researchers will likely play an important role in validation studies that will be done in connection with use of XR in Norwegian schools and institutions of higher learning.

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[27] A cluster of businesses working with VR, AR and gamification in Norway. Accoring to VRINN-- https://vrinn.no/-- "The cluster exists to create major international innovations, helping the businesses market, grow and develop themselves and fuel the future of work for organizations and businesses. The main focus areas within the VRINN cluster is "immersive learning" – how to use 'immersive' technologies like VR and AR in learning, training education and knowledge transfer in general – but our **members** work within a wide range of disciplines including the health care sector, crisis management, decision making and operational support."

Box H

XR-education at INN-Game School

As noted earlier in this section, one of the features of the Hamar region that caught the attention of EON Reality when it was looking for where to place its Norwegian HQ, was the strong gaming hub that existed around Hamar, including the Department of Game Development, Game School at INN (the Inland Norway University). The Game School works with games and XR not just directed at entertainment, but uses gaming and XR competences also in a number of other education and learning applications.

While the focus of much of the School is on game development—hence the name—but much of the education and learning in the Department helps build competencies like 3D, animation, game play, programming, and gamification that are keys to all good XR experiences, whether gaming or education and learning. According to Institute Leader Marit Berg Strandvik, these competencies as part of the XR education helped convince the county, the municipality, and EON Reality and the rest of the partners to invest in the XR-cluster where the University also would establish a new XR-program (Add-on Program in Virtual and Augmented Reality) in collaboration with EON Reality to start build new competences.

The XR competencies built in the INN-Game School are also attracting a great variety of projects and collaboration partners from a wide range of institutions and companies, both in Norway and from other countries. The projects range from tourism, sport analyses, geology, teacher education (practice simulator), leader management, VR for treatment together with Inland Hospital, Implementing AR/VR as supplement in High School—courses for students and employees followed by research, VR-projects for awareness and capacity building for different target groups, etc.

The significant XR competence in the Game Department at the INN University and the extensive project experience already gained and continuing to build in collaboration with the cluster partners, gives the University a position as the leading XR academic institution in Norway.

Table 2

Selected XR Projects at Department of Game Development, Game School

Project Name	Brief Project Description/Funding
Gaming Against Depression: An Effective and Drug-Free Virtual Reality Treatment for severe Depression	Training in a virtual environment with VR, in collaboration with Inland Hospital, funded by RFF
Active professional development in a virtual world	Development of practice simulator in VR. Virtual world with MoCap (See section 5.3.1.1). Scenarios for difficult conversations between teachers and students. Funded by DIKU, in collaboration with EON Reality and Faculty of Teacher Education and pedagogy
Knowledge tourism in Inner Scandinavia - dissemination of natural and cultural monuments using virtual and augmented reality technologies (VR / AR)	Funded by RFF, in collaboration with many partners.
VRGoGreen	Developing and testing mental health-promoting VR systems, in

	collaboration with Faculty of Public Health, INN
Upscale good practices towards combating violence against women and girls	Training in virtual environment with VR, in collaboration with EON Reality. Funded by UN and Innovation Norway.

5.3.1.1 Private-Public Partnership

Figure 4 and Table 2 below, identifies the main players that came together at the meeting in Hamar in late 2016 to agree on a plan that has helped shape subsequent developments and building a foundation for further growth of the gaming and XR industry in the Hamar region and beyond. All of this, at least in part, was triggered by the arrival of EON Reality[28] which planned to establish its Norwegian headquarter in Hamar, partly in recognition of the region's gaming cluster and the inland university (INN). EON saw the strong gaming hub and INN's focus on new media and gaming, as important strategic resources that it could leverage in its future growth (similar conditions and think also contributed to EON's choice of Viborg as the center of its Danish establishment, discussed in section 4.1.3). As part of EON's activities in Hamar, it established an Interactive Development Center (IDC), one of a large number of similar IDCs the company has established around the world (see more on this below).

EON's arrival in Hamar acted as a major trigger for a number of XR-related developments, including:

- *XR Certificate at INN*. A new 1-year program was created for students who had completed their bachelor studies, to gain specialization in XR. EON Reality Norway has contributed expertise and teaching resources to this program. At the conclusion of the fist year's program, when 23 students graduated, the bulk of them gained jobs with EON Reality Norway.
- *Opening of PARK*—a startup and business house/Hub in Hamar. Around 200 people are now working in PARK, including VRINN, which in part organizes the annual Nordic VR Forum that takes place in Hamar (attended by over 300 people from 10 different countries in October 2018). The hub includes game development, education, and XR technologies, all under one roof. PARK also has a new Motion Capture Studio known as INN MoCap which is the largest and most modern of its kind I Norway.

Figure 7

Structure of Hamar's AR/VR Private-Public Partnership

[28] EON Reality is a large US technology company with focus on AR and VR with HQ in Irvine, California. The company has long served a wide range of industrial companies with advanced technology solutions, but has also built a significant AR/VR educational position, helping build the next generation of developers through its VR Innovation Academies, etc. The company's European HQ is in Manchester, UK.

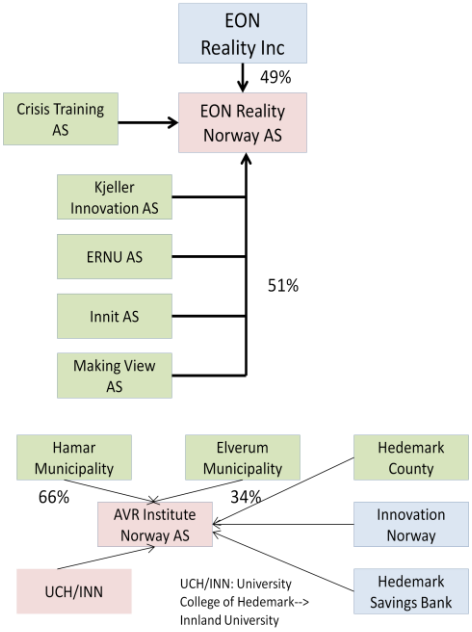


Table 3

Founding Organizations of the Hamar AR/VR Private-Public Partnership

Organization	Brief Description
EON Reality	See Footnote 28
Crisis Training AS	Organization which ERNU AS [see below] and Kjeller both are contributing expertise and resource in order to build next-generation crisis training products and services
Kjeller Innovation	R&D organization located in Kjeller Research Park in Lillestrøm and with close ties to various Norwegian research centers; http://www.kjellerinnovasjon.no/about-us/
ERNU AS	Economic development organization for the Elverum region; http://ernu.no/
Innit AS	Technology-based service company in Hamar; https://www.innit.no/om-selskapet/
Making View AS	Hamar-based technology company offering XR Learning Ecosystems and various 360-degree products and services; https://www.makingview.com/#/Home/
Hamar Municipality	Municipality of city of Hamar and home of around 50,000 people
Elverum Municipality	Neighboring municipality of Hamar, with estimated population of 21,000 people
Hedemark County	The county administration of the cities of Hamar, Kongsvinger, Eleverum and Tynset. Hedmark is one of the less urbanized areas in Norway. As part of Norway's ongoing consolidation of counties, Hedemark and Oppland counties will merge into Innlands county in 2020; https://www.innlandetfylke.no/
Innovation Norway	The Norwegian Government's most important instrument for innovation and development of Norwegian enterprises and industry; https://www.innovasjonnorge.no/en/start-page
Sparebanken Hedemark	Local savings bank focused on the Hedemark county
UCH-INN	Inland Norway University of Applied Sciences, with a number of campuses in what will become the new Innlands county in 2020; https://eng.inn.no/
AVR Institute AS	Owned by municipalities of Hamar and Eleverum, and with funding or resource contributions by other organizations as shown in Figure above

5.3.1.2 EON Reality: Role and Vision

EON has a long history of building innovative technology-based solutions for a wide variety of companies and industries, and has expanded rapidly internationally, now operating in 30 locations around the world. In addition to building technology platforms—Creator AVR (Augmented and Virtual Reality), Virtual Trainer, and AR Assist--for its XR solutions, EON has also over the years built up a strong XR education operation, consisting of a global network with the following operations:

- *EON Reality Education*—This is EON's non-profit entity to advance the cause of XR (EON prefers to use the term AVR—for Augmented and Virtual Reality) education and research. To strengthen this operation, EON has been placing academics or former academics with strong learning and technology reputations to evangelize around "next-generation education and learning" (using technology)
- *Interactive Development Centers (IDCs)*—These are "AR/VR design & development facilities equipped to stimulate the community, support the regional talent, and progress business activities," and Hamar has the only IDC in the Nordics (a total of 19 exist around the world: 7 in the US, 1 in the Caribbean, 5 in Europe, 2 in Middle East, 2 in Africa and 2 in Asia).
- *VR Innovation Academies*. EON sees these as training centers, within the IDCs, designed to provide hands-on learning in the design & development of XR. Typically, these Academies—such as the one in Hamar where EON is working closely with INN staff—typically has two parts, each lasting around 4 months: (1) General Knowledge Transfer: Addressing fundamental XR skills; Scripting techniques; 3D modeling & animation; Immersive systems; Mobile applications; and Project management; (2) Project-based Learning (typically lasting from 4 to 6 months): Creative workshops; Portfolio development; Projects; Industry Exposure; and AVR platform. The first of these program parts result in the EON Certified Developer Certificate, Level 1, while the second program yields EON Certified Developer Certificate, Level 2, with 3 different possible specializations: Generalist, 2D/3D Artist, and Developer.

In view of EON's almost 20 years of experience in developing advanced XR technologies and solutions from over 1,000 projects for clients (mostly large industrial enterprises) and its growing global presence in educating and training the next generation of XR developers, the company is an important player in the Norwegian XR ecosystem. It already has helped trigger and stimulate additional energy around the building of XR development around the Hamar region and will likely continue to be a strong collaboration partner for INN and smaller Norwegian XR players, such as VR Education and others that target Edu applications.

5.3.2 NTNU: A Leading Academic XR Player

Although a number of Norwegian universities are now active in XR and have labs that are exploring a variety of research areas and potential industrial applications, NTNU, as the leading Norwegian technical university (but University of Agder and others now have excellent tech and science research in a number of areas), has the most active XR activities. NTNU's VR labs also collaborate with other academic institutions both in Norway (including with VRINN) and other countries, including in EU-funded projects. New XR research projects will likely launch in the near future, with domestic funding, including the Norwegian Research Council and private industry. Other projects will likely be connected with EU and

other funding for consortia of institutions, and some of these NTNU projects will likely be directly or indirectly related to XR-Edu.

The following are brief descriptions of VR Lab operations at NTNU:

- *Innovative Immersive Technologies for Learning (IMTEL)*. This is a research group at the Department of Education for Lifelong Learning. The research group is headed by Professor Ekaterina Prasolova-Forland, and group members include Professor Leif Martin Hokstad, Researcher Mikhail Fominykh, Associate Professor Ingunn Dahler Hybertsen and Postdoc Fellows Ida Marie Lysa and Jenny Melind Bergschöld, with a new postdoc joining the group shortly. The group is the only one in Norway performing systematic research on XR for learning and training and also develops educational VR/AR apps for teaching various subjects (e.g. math, language, history, medicine and climate change) and for career guidance in collaboration with corresponding research environments and industry/public sector. The IMTEL group has founded and actively uses 'Lifelong Learning' VR/AR Lab at Dagvoll campus that is now a part of the NTNU VRLab network (see next bullet and see Table 3 showing selected projects of IMTEL and VRLab). The group hosts regular 'Innovation days' and lab visits, with the goal to present the potential and advances of XR technology to NTNU students and employees and general public.
- *VR Lab*. This is a network of innovative VR labs, each of which has unique characteristics, connecting NTNU campuses in Trondheim, Gjøvik and Ålesund and facilitating meetings in VR. IMTEL VR/AR lab Dragvoll in Trondheim is focused on learning and is equipped with the latest XR equipment. The lab gets considerable use by Bachelor and Master students in domains such as IT, geography, pedagogy, psychology, cybernetics, biotech, pedagogy, and teacher education. The Dragvoll lab is also used by the "Experts in Team" course "VR/AR in learning and training".
- NTNU has also an extensive XR network with regular meetings (organized by Professor Andrew Perkis) and is a part XR Norway cluster.
- Recently, NTNU and SINTEF [a large applied research, technology and innovation organization with HQ in Trondheim) submitted a joint application for a 'Gemini' center to strengthen collaboration in the XR field.

Table 4

Selected IMTEL Projects at NTNU

Project Name	Brief Project Description/Funding
Virtual Internship in VR/AR	Providing young job seekers with an immersive 'Job Taste' of different professions and job interview training in VR. The project won Best Demo Award at EuroVR 2018 conference and was finalist of the Breakthrough Auggie Awards 2018 and received extensive media coverage. Funded by grant by Norwegian Labor and Welfare Administration (2017-2019)
FUTURUM	Visualization of climate change in the city of Trondheim in VR (VR headsets and VR treadmill), to be demonstrated at the Big Challenge festival. Funded by the Norwegian Research Council
Virtual Arenas in Medical Education (VIRSAM)	Training in health services collaborative work in virtual environments, grant from Norwegian Research Council FINNUT (Research and Innovation in the Educational Sector) program, (2017-2020), in collaboration with other partners.
Active Learning Module for Emergency	Interprofessional Emergency Management Training in VR. Funded

Management Professionals using VR	by grant by Norgesuniversitetet (2016-2018)
TARGET	Serious games for transformative, adaptive, responsive and engaging environment for corporate learning, funded by EU FP7 (2009-2012)
BioWaveVR	Therapy with Virtual Reality and Wearable Technology, in collaboration with St. Olavs and Coperiosenteret; grant by Helse-Midt-Norge (2016-ongoing)
CAMO	Cultural Awareness in Military Operations, Norwegian Armed Forces (2011-2012)

Source: NTNU

As a leading academic research partner of Norwegian industrial firms, including especially large oil and gas companies, such as Equinor (formerly Statoil)—and often in collaboration with SINTEF (a large R&D organization also located in Trondheim)—NTNU has built and used other XR technologies, including RAVE. Norwegian oil companies helped fund the building of NTNU's CAVE facility, and Norsk Hydro used NTNU's CAVE technology to visualize reservoirs, and used it to plans for the exploitation of the Troll field in the North Sea. Other XR technologies are now providing much of the affordances of CAVE and have therefore greatly displaced the need (and high cost) of CAVE.

5.3.3 Other Norwegian AR/VR Ecosystem Players

The discussion above only highlights a few of the major XR players, especially those with significant activity relating to XR-Edu. But here are some others that have some direct or indirect XR activities with current or potential Edu connections:

- *VR Lab at Norwegian University of Life Sciences (NMBU)*. This university has similar strength in life sciences as NTNU has in technology and engineering. It is located near Oslo and has around 5,000 students. Its VR lab is used for visual simulations, education, architectural design and landscape planning (including a joint project with UC Berkeley), creation of artistic applications, reconstruction of historical sites, and testing of new 3D technologies. They also report on having started working with VR as an educational tool in schools, and hopefully we will see reports they will make public on their findings, including lessons learned in the XR implementations they examine. One area in particular that they have been exploring is "facilitating experimentation environment for development of a new VR application for molecular biology course at the department of Chemistry, Biotechnology and Food Science." Comparing the lessons from this with the lessons gained in RUC from using Labster would be interesting.
- *HaldenVR Center*. Halden Virtual Reality Centre (HVRC)—part of the Institute for Energy Technology (IET)—was established in 1997, as a section in the Visual Interface Technology Division of IET, and is an international centre for research into XR technologies focused on the application of both emerging and maturing 3D technologies to address the needs of industries that manage complex processes. The Center notes that the VR Lab is both an experimental facility for studies and a test bed for new applications, but is also actively used for tech demonstrations and as a teaching facility. HVRC notes that "We have a close cooperation with both staff and students at Kyoto University in Japan, Norwegian University of Science and

Technology (NTNU), Oslo School of Architecture and Design (AHO), and Østfold University College (HiØ). We have also hosted student projects, given lectures, and participated in projects with many other universities around the world."

- *Noroff School of Technology and Digital Media*. At Noroff, its university college (offering Bachelor degrees) offers degree specialization in Interactive Media—Animation of Gaming—and its Vocational School ("fagskole") offers a range of courses, such as VFX/Visual Effects, Technical Design with 3D, 3D Design and Animation, 3D Game Design, and 3D Film Production.
- *Industrial users and government*. Many companies in a number of industries around Norway, are using XR technologies or are considering their potential use. Some of these users have been noted earlier, as some of these companies have teamed up with academic research partners, including NTNU's VR Lab, NMBU and HRVC. And a number of hospitals and medical centers are among those exploring how XR can best be use, especially in therapeutic applications but also for planning or execution of various forms of medical intervention. Many companies, such as Statnett (the Norwegian energy network) use of 360° video for a number of different applications, either in operations or marketing, for example. Finally, the Norwegian armed forces and seriously exploring the use of digital twins and distributed virtual training (and similar developments are also seen in many other countries, including the US).

Box I

VR Education: Teaching Math through VR

By Per Olav Nyborg, VR Education CEO, Norway

Company Background. The idea for the company was born inside a Norwegian publishing company, Kommuneforlaget (KF AS), which has long served Norwegian schools and other clients with textbooks and other educational materials. So the company had strong knowledge of the market and institutional side of Norwegian education system, as well as insights into what areas were in need of innovative solutions. When the idea emerged of using VR to address a major "pain point in Norwegian schools"—learning math—the company figured it could draw on some of its own core competence, as well as technology expertise from local startup companies in the Hamar region that could help make VR Education successful. In January 2018, KF AS decided to spin the VR venture out (and retain an equity interest), and VR Education was born—with 2 employees. The founding partners were Making View AS (a Hamar-based XR company that has pioneered 360° video since 2010) and Innit AS (another Hamar-based IT company). These 3 founding partners collectively have 100 employees and revenues of €15 mill. in 2018.

Learning Context. As noted above, low achievement and skills in mathematics in Norwegian schools was the starting point for the project that led to the launch of VR Education. Norwegian students have lagged behind in mathematics testing at grades 4 and 8 in the PISA assessments. But this is not a uniquely Norwegian problem and solutions would likely find appeal in many schools around the world. A VR-based solution would help student focus on the problems at hand, and minimize distractions that exist in most classrooms today (Norwegian studies have found that effective learning time may be as low as 40-45% of classroom time). And the pilot studies that VR Education has done so far, show that students not only gain greater focus but are also much more engaged in the math lessons, partly by using some gamification elements that introduce a fun element into the learning process.

The VR Education solution allows teachers to monitor each student, on the basis of assignments and how they progress over time. The solution also provides teachers with more time to teach, because the lessons are automated and corrected automatically. And the technology makes it possible to track how quickly a student responds, the student performance, relationships between correct and incorrect answers, and how much time students spend on particular lessons. Learning and student data collected over time can also be analyzed to give insights into specific issues of the learning process.

What's Ahead. So far, a six weeks pilot study involving four different classes of 5th graders in mathematics, focused on multiplication, has been done. The test has been monitored by Practice-Based Education Research Center (SEPU) at Innlandet University College and a preliminary report has been written. The results have been very encouraging, but more data are needed and further testing with more pilot schools will be performed the spring of 2019. We have started to sell the product in the market and the company now needs to deal with distribution and other logistics, and must cope with fast changes in the hardware market and how to scale the company rapidly. So far, the company has gained a great deal of media attention, even with the Norwegian Prime Minister asking for and getting a product demonstration during the Nordic VR Forum event in Hamar in September 2018.

5.4 Sweden

Sweden does not have any universities in the VR First network, and it only has an EON Reality administrative and marketing office in Sweden, but nothing like the public-private partnership structure that EON has established in Norway, and more recently in Denmark. But Sweden, like Finland and Norway, also has a VR/AR Association chapter. Niclas Johansson of VRSverige.se agreed with my assessment that Finland seems to have the largest/strongest XR ecosystem in the Nordics, and credited Tekes as one of the major support organizations helping to fund both research projects and studies (although as discussed later in this section, Vinnova has played a similar, but likely smaller role in Sweden to what Tekes has done in Finland). Johansson also noted **that "**the kind of project support that Finnish XR is getting for education projects etc, esp from Tekes, is missing in Sweden." He added that "vertical industry solutions are missing in Sweden. There are agencies that do on-spec, customized and proprietary solutions for various companies and industries, but the tech and solutions are then owned by client, and the solutions will not be scaled up and made available to industry in general."

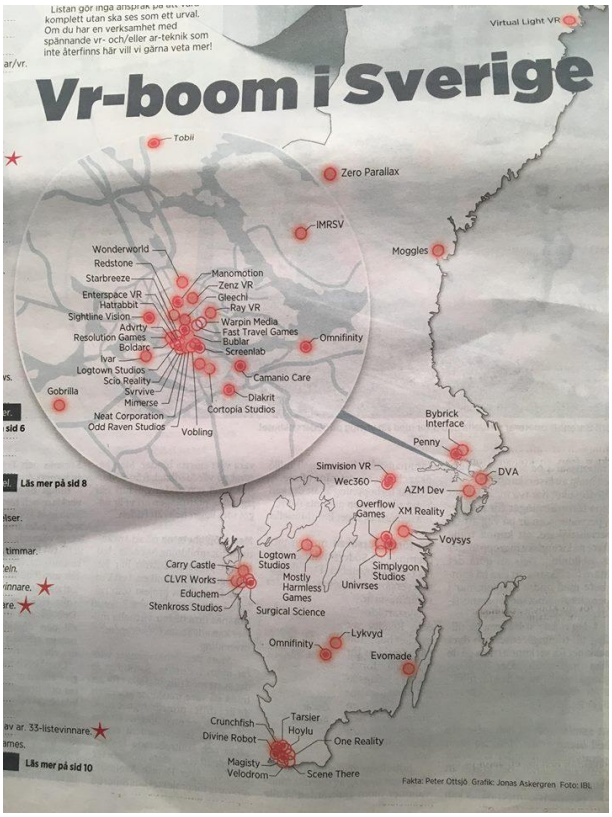
According to an analysis by Neil Murray of XR investment in 2016--more recent data are not yet available—Sweden did get a greatest number of XR investments (4) in the period Q1-2015 to Q2-2016 than Norway and Denmark (each got 2). Murray did not have the value of XR investments, however. Another insight from Murray regarding these XR investments was that less than half of XR investments in the Nordics during the period went into gaming startups.

From an analysis done in 2017 by two reporters (Kalle Wiklund and Peter Ottsjö) from the technical publication NyTeknik of VR activity in Sweden, their findings show a number of VR companies—mostly early stage companies—similar to what the VRAR Association chapter in Norway found (and reported on in the section on Norway). The geographical distribution of the 63 companies found by the NyTeknik team, are shown in Figure 8 below, and shows, not surprisingly, a considerable concentration in VR operations around Stockholm, and with the bulk of VR operations to the south of Stockholm. While the NyTeknik report does not show how many of the 63 VR firms have either direct or indirect involvement in Edu-focused activities, they note that a popular vertical is medical and health.

As in other Nordic countries, many of Sweden's XR companies are also focused quite a bit on entertainment and gaming, and this focus may make sense given the considerable success many firms in the Nordics have had around entertainment and gaming over the last decade. However, creating successful games—and building sustainable success in this vertical—is very challenging. And adding additional risk by trying to leverage emerging technologies like XR, brings new challenges, especially when gamers excitement for XR is still "work-in-progress." Nordic proof of this challenge can be found in the Swedish gaming company Starbreeze, which developed a very high-end (very high definition images) HMD known as Star VR. The company announced in late 2018 that it had "filed for reconstruction," making the future of its VR Tech and Operations division uncertain. As will be seen in the section on Iceland, that country's VR-focused gaming has also hit a "pause button." Whether and how this may affect Edu-focused XR developments in either Sweden or Iceland is still unclear.

Figure 8

Swedish VR Operations



Source: Kalle Wiklund and Peter Ottsjö , NyTeknik

Box J

A Swedish Edupreneur's Perspective on VR Journey

By Jonas Bostrom, Ph.D., Founder and CEO of EduChemVR

What we do @EduChemVR. We develop and provide efficient learning experiences beyond today's traditional teaching tools – the pen, paper and textbooks. More specifically, our goal is to improve chemistry education with easily accessible digital tools. Most often, in the form of virtual reality content. Our current target is K-12 and University level. In the future we will also develop for younger students. The main focus is on keeping it simple and inexpensive to be able to reach anyone, everywhere. Thus our focus is on content for smartphones and Google Cardboard-like VR goggles.

Challenges. Pioneering a field in new ways comes with two faces. On the upside, it is a truly awesome feeling to be at the forefront influencing and being part of driving EdTech development. But as rewarding the upside is, as frustrating is the other side of the coin. Educational systems are, on the whole, unfortunately very slow adapting to the future. Take Sweden, for example, which is known as an innovative tech friendly country. In my daughters' middle school in the Gothenburg city center (the 2nd biggest city in Sweden), there are red signs saying "this is a mobile free school" everywhere. C'mon, it's 2019. Strange to forbid, would be better to educate how to use them. My son, who attends 8th grade in one Gothenburg's biggest schools, still hasn't seen a computer in his class-room. No computers present in any of his school subjects!

There are, of course, exceptions. Some schools are more tech friendly. But the traditional old-school way to teach, using books and the black/whiteboard still dominates. This is frustrating, since we *know* digital education is (part of) the future. Why would anyone not use digital content in education? It's faster, more efficient and better. In chemistry we can show the "unseen" using digital media. We can shrink students and teleport them to an atom scale and let them enter a molecule. Time can be slowed down to allow very fast processes like chemical reactions to be observed. Compare experiencing chemistry in 3D as dynamic process as compared to seeing static pictures drawn on a piece of paper. I can go on. But there is hope, as we do see a constant increase in interest and more and more teachers contact us and the scene is slowly changing.

For us, another challenge is that the virtual reality field has not matured yet. The high-quality systems (such as HTC Vive, Oculus Rift, MS mixed reality) are still perceived too expensive to become mainstream, and the inexpensive systems (e.g. Cardboards) may not always be so impressive. There's constant progress though, and great to see the energy and enthusiasm among the VR/AR developers. And there are indeed constant advances in tech development. My co-founder and I have been active in the VR/AR field since 2015, and it's cool to see the changes. An advantage is that we learn how to best develop. Our collaboration with Moscow and Umeå University are rewarding and great to have. The Umeå team consists of teachers, professors and pedagogs. Perfect for helping improving our tools, and in the latest user survey, their students in our pilot reported "Most students were satisfied or very satisfied with today's workshop on orbitals. They thought it would be good to use it earlier in the education". So far, and since we have decent day-jobs (Nasdaq and Big Pharma), we are working with this (EduChem VR) on (all) our spare time. It shouldn't escape anyone that we're in it for the long haul. We love doing this, and when we see schools across the globe are ready, we'll switch gears and go all in!

5.4.1 Vinnova: Applied Innovation Focus

Some of the companies identified in the survey done by the NyTeknik reporting team may have been part of some of the VR projects funded by Vinnova—the Swedish research funding agency (Similar in operation to Tekes in Finland, but with a smaller budget than Tekes)—which has taken a strong interest in XR, especially in recent years. Some of the Vinnova-funded projects involving XR, including some with Edu focus, are shown in Table 4 below. While some of the projects shown are focused on skill and competency development—and training (one project specifically targeting the process industry)—most have only indirect implication for Edu, but insights and lessons learned in the projects may well have relevance for how XR could find best use in Edu applications. In addition to helping validate how useful XR would likely be in particular types of applications, the projects also help create greater awareness and understanding of XR both by research organizations as well as in participating industrial use organizations.

Table 5

Selected VR Project Funded by Vinnova

Project Title	Project Date	Organizations Involved	Brief Description
VR-based Competence Development in Process Industries	2017	• Gleechi AB • Lernia	Goal is to create prototype for VR training that Lernia can use to make Swedish industry more effective and give Lernia a scalable platform for growth
Seeing is Believing—Equality Through VR	2018-2019	• Cybercom SwedenAB • Olika AB	VR will be used to examine the "Workplace of the Future" based on non-traditional norms and practices
VR Assessment Center—From Physical to Virtual Assessment	2017	• International Talent Management AB	Create a tool to assess or train people before deployment into emergencies by simulating the emergencies with Virtual Reality technology
Trollsaga—A Unique VR-game that improves player's empathy skills	2018-2019	• Antler Interactive[29] -- • StoryUp	The objective is to develop and test a prototype for an empathy-inducing VR game, aiming to result in a methodology for empathy-improving game design for a global market
D-escalator/violence Prevention, VR Simulator	2017-2018	• Framvik Productions – • 10-15 other organizations in Sweden and US participating in project	Project will develop a prototype for employee training and development, including a training similar using VR as tool to reduce workplace conflict and violence
VR Fear and Anxiety Assessment Platform	2016	• Mimerse AB	Goal is to develop, test and validate a VR-based tool for treating fears and phobias

Source: Vinnova

5.4.2 XR at Swedish Universities

[29] Formerly SVRVIVE Studios

Although no universities were involved in the Vinnova projects shown in Table 4, this is because most of Vinnova's projects tend to fund innovation projects that are more application and market-oriented, rather than more "basic research oriented" which one finds in most university XR research. As I found in Finland and Norway, Sweden also has a number of active XR labs, and some of the XR work takes place not in special XR Labs, but as part of related fields (such as scientific visualization at the Linköping University, for instance—see below). Interestingly, Chalmers University of Technology (in Gothenburg)—one of the leading science and technology universities in Sweden (and which hosted Reality Software and Technology Conference)—appears to have relatively little going on in the XR area. But of course individual professors at Chalmers as well as at University of Gothenburg and other universities can be found in departments and centers like Human Computer Interaction Department, Department of Computer Science and Engineering, and Architecture and Engineering, among others, that do work that relates to XR, but most of this work has little Edu focus, at least directly[30]. The School of Information and Communications Technology at Chalmers hosted a public demo of XR in October, 2017, but a long list of interesting research projects in the School of Computer Science and Engineering show none with any mention of XR.

Some of the Swedish Universities or University Colleges that are doing work that relates directly or indirectly to XR, or have had activities in recent years, include the following[31]:

- *VR-Humanities Lab and VR-Lab in Design Sciences, Faculty of Engineering, Lund University*. The Humanities Lab has, in collaboration with the VR-lab at Design Center, a cave, consisting of three walls and and a floor with stereoscopic 3D and head tracking, for a visual reproduction of models. While the Humanities lab deals with topics within archaeology, cognitive science, theology, communication studies, and cognitive psychology, the Design Sciences see its VR lab as an interdisciplinary meeting point for visualization and new interaction technologies. The lab has partnerships in the academic world, in terms of research projects and courses, and in the private and public sectors. Table 5 shows some of the types of questions that the Design Sciences VR Lab explores.
- *VRxAR Labs, Linnaeus University*. The VRxAR Labs research group, focuses on understanding how humans behave when operating within virtual environments that enable exploration and interaction with data. The vision of the group is to contribute with ideas and solutions to create usability-friendly experiences for the future. These research topics are highly relevant for academia, industry, and society as 3D interaction is fundamental for real-world tasks. Selected projects of the labs include: Augmented Reality for Public Engagement; Open Data Exploration in Virtual Reality; and Exploring Virtual Reality as an Effective Learning Tool[32].
- *Scientific Visualization Group, Linköping University*.[33] Among the activities that are directly or indirectly in XR is the university's work in partnership with a number of other organizations to make Visualization Center C into a major research and science center in Norrköping, Sweden, as well as engaging in public outreach activities. Areas that the center deals with include such things

[30] Many students at universities in the Nordic and Baltic universities are also likely involved in their own XR projects, but to our knowledge, no data on such projects are available.

[31] Another university with a new VR Lab is the University of Gävle)—about 50 miles north of Uppsala--and no doubt can also be found in other parts of Sweden. For more about its VR Lab see here

[32] Interestingly, a 2015 Master Thesis at University of Gothenburg was on "The Benefits of Virtual Reality in Education: A Comparison Study" by two students in Software Engineering and Management; See here

[33] Another area of research in VR has been done in Linköping University's Media and Information Technology Department is "Finding Space for Augmented Reality." A group of master's design students working with visual media addressed how AR can be used to challenge social norms. See here

as immersive display environments, stereoscopic 3D technology, interaction design, information and geo visualization, ambient visualization, and exhibition design.

- *Human-Centered Visualization Group, the Department of Computational Science and Technology, KTH.* One of the projects done (in the period October 2016-September 2018) in this group was entitled "Context-Aware Augmented Reality Experiences in and Beyond Museums[34]." This project, done in collaboration with a number of partners, appears similar to the VTT's MIRACLE project discussed in Box E, but that project was focused on VR and the KTH project was AR focused.

Table 6

Questions Explored in Lund University's Design Sciences VR Lab

• Can the visualization of buildings and living environments support urban planning?
• How can we visualize and experience our cultural heritage?
• Do virtual natural environments have a beneficial effect on people's health?
• Do virtual avatars have a function in the survey of stress reactions?
• Do virtual models support the planning of future healthcare settings?
• Can visualizations support the discussion of how work in the future will be organized?
• How do we create a sustainable city?

Source; Lund University's Design Sciences VR Lab

5.5 Iceland and the Baltics

As will be seen in the sections below, these countries seem to have somewhat smaller XR ecosystems compared to those we have described for Denmark, Norway and Finland—perhaps partly reflecting the size of the countries (and therefore, the number and size of schools and universities). But Estonia, especially, has considerable XR research activities and interesting projects. And Estonia, in particular, is known for strong government support for schools and higher education institutions, and having strong technology infrastructures and an attractive startup environment which has helped raise capital for new XR startups.

5.5.1 Iceland

For a country of only around 340,000 people, the country has for years been "punching above its weight," particularly when it comes to XR innovations around gaming and futuristic music entertainment. So far, it is not clear to what extent these developments (more below) have impacted, or will impact, the use of XR in schools or universities. So far, few signs have been found that this is yet happening, and no major government/ministry-funded initiatives like those I have described for Denmark and Finland, in particular, or government research funding agencies, like Tekes and Vinnova, have yet been found for XR in Iceland.

5.5.1.1 XR-Based Gaming

[34] See here

For a while, it looked like Iceland would be leading the way in XR-based gaming by leveraging the world-class gaming expertise of CCP Games, the company behind the highly successful multiplayer game Eve: Valkyri (as well as Eve Online and other successful games). The company intended to show how engaging, innovative multiplayer immersive games could be built in VR, and showcase "next-generation games." Significant resources were invested in VR games during the years leading up to the dramatic announcement in October, 2017 that CCP would stop making VR games, and drop two of its studios. CCP executives made it clear that they had miscalculated the readiness of markets and, more specifically, gamers' readiness to embrace VR in gaming. According to the company: "We will not be making material VR investments until we see market conditions that justify further investments beyond what we have already made." And the executive noted that CCP planned on staying out of VR for the next two to three years. According to CCP, the overall market remains too small for large teams to profitably develop for it, and according to The Verge, "it's not surprising to see a VR-heavy studio refocus — and, in this case, make big cuts along the way."

But CCP did not close its VR division and indicated it would continue to monitor the VR technology evolution and be ready to jump back into the VR-based gaming market if and when they felt sufficiently large number of gamers playing VR games existed, to yield the needed profitability of the games.

However, about a year after pulling back from their VR project (i.e. in early September 2018), CCP announced that the company had been sold to Pearl Abyss of Korea (the creator of Black Desert Online, among other games), an aggressive player that has been building a growing global presence in games. The Korean company saw the opportunity to acquire great game-making talents and innovative skills in the CCP team. What this means for the future of VR-based games, especially in Iceland, and whether Pearl Abyss will support such a strategic move, and when, is highly uncertain.

But CCP has not been alone in Iceland in building VR-based games. Another well-known studio with strong capability in this area is Solfar Studios. This company has found Asian and Nordic investors willing to support their VR-based gaming strategy[35]. The company made clear that it would "…create trailblazing content for this medium of the future [i.e. VR]," but this statement was made almost 2 years before CCP admitted to its market miscalculations (and Crunchbase shows no new capital coming in to Solfar over the last few years). Thus it will be interesting to see if they are finding sufficient market support for their games to prove to their investors that these types of leading edge, VR-enabled games can be sufficiently profitable.

5.5.1.2 XR and Music

The second area where Iceland has shown how to leverage emerging technology like VR can be used in new and creative ways is in music. Iceland is well known for having some very creative and leading edge musical artists, including Björk Guðmundsdóttir (known only as "Björk"), who is an "Icelandic singer, songwriter, composer, actress, record producer, and DJ. Over her four-decade career, she has developed an eclectic musical style that draws on a range of influences and genres spanning electronic, pop, experimental, classical, trip hop, IDM, and avant-garde music." Björk has been demonstrating how emerging technology can be used in artistic enterprise, and according to one report, in a press conference for her "'Björk: Digital' exhibit in London, "she appeared to a room full of journalists as a live

[35] An article in Inc.com in December 2015 noted that "In 2015 alone, two Icelandic gaming startups received a total of $32 million in venture capital, as they bring their VR concepts stateside."

motion capture VR apparition, which was beamed from the Reykjavík School of Technology, and saw VR move into a new sector of pop culture."[36]

5.5.1.3 XR in Universities

An examination of the many research institutes and centers at the two largest universities in Iceland—University of Iceland (a public university and by far the largest, with around 14,000 students) and Reykjavik University (a private university, with 1,400 students) found nothing to indicate any XR project activity. But since many of the institutes and centers are, at least in part, focused on emerging technologies and innovative applications of these technologies, XR research may well be done by individual professors, but not highlighted publicly by the university (This is also true in Umeå University in Sweden, where a number of professors and researchers have been actively exploring the role of VR in learning and teaching, but the university as a whole having no formal XR facilities or research groups).

Since one would expect research interest by faculty and students, especially graduate students, to at least partly reflect what Iceland's innovative startups are doing, it is likely that either business or technology research projects may be under way in the two leading Icelandic universities. This could also be the case of, for example, the Center for Educational Research on ICT and Media, where XR-Edu would be expected to be found. XR related projects may also exists in some of the other, smaller institutions, such as Iceland Academy of Arts (as AR or VR is increasingly being used to create unique and innovative artistic experiences, as shown in Unreal Gardens in San Francisco, for example, or in music artistry as discussed earlier in the case of the Icelandic musician Bjork).

5.5.2 The Baltics[37]

In edtech, the young Estonian entrepreneur, Märt Aro (of DreamApply, a successful Estonina edtech company) took the initiative to create a "Pan-Nordic" organization of Nordic and Baltic edtech founders and CEOs, and called it N8 (for the 5 Nordics plus the 3 Baltics). I applaud Märt, and know him to be an "action oriented person," and hope someone like Märt, with strong interest in XR will emerge to help build and shape a Nordic + Baltic XR community with XR entrepreneurs, researchers and educators with interest in the future of XR in education and learning. Since the Baltics are increasingly connecting to the Nordics—and Estonia has had strong links with Finland, especially, for many years—a Pan-Nordic/Baltic XR community should have the potential to help accelerate XR-Edu developments in the region. As shown below, there are many organizations and individuals, and projects that can be leveraged across the region, as many are likely to be complementary with some of those identified for the Nordics, and thus create synergies that can benefit the region as a whole.

5.5.2.1 Estonia

[36] Interestingly, while this report came from The Reykjavik Grapewine, as far as I can tell the "Reykjavik School of Technology" does not exist!

[37] The research of XR in the Baltics was done by Teele Jürivete, a Specialist in Augmented Reality at the Institute of Education, University of Tartu. She is a member of the research team of Margus Pedaste, Professor of Educational Technology at the Institute of Education of the Faculty of Social Sciences at the University of Tartu. Many thanks to: Arnis Cirulis (Vidzeme University of Applied Sciences, Latvia), Janis Kondrats (Anatomy Next), Mantas Lapinskas (Kaunas University of Technology, Lithuania), Raminta Rupeikienė (Vilnius University, Lithuania), Gholamreza Anbarjafari (University of Tartu, Estonia), Vladimir Kuts (TalTech, Estonia), Aleksei Tepljakov (TalTech, Estonia)

There is a small, yet active community of XR professionals and enthusiasts in Estonia who discuss related topics on their Facebook group and organize regular meetups. The community also has a website in English, which collocates lists of enterprises, research initiatives and people involved in the field in Estonia. Among other activities, the community has created an AR/VR English-Estonian dictionary to explain terms related to the field in Estonian and to create a corresponding vocabulary in the local language. There are various initiatives in XR-Edu supported both by national and international funding schemes and the projects span from K-12 to higher education.

5.5.2.1.1 XR in K-12 Education

One of the main organizations leading innovation in Estonian educational system is Information Technology Foundation for Education (HITSA), a governmental body promoting and supporting meaningful use of information and communication technology in education. The main activities of HITSA include organizing training, talks and providing support for schools to purchase technological equipment. HITSA also works in cooperation with entrepreneurs and educators to raise awareness about various technologies and its potential for education among teachers and educational technologists. In February 2019, the organization published a report on technological trends for education (including also XR), targeted towards local educators to raise awareness about the technologies. As a part of the report, HITSA carried out a survey among schools to map educators' awareness about the technologies, how often and for which purposes these are used in schools and plans for the future.

The results of 61 schools reflected that XR technologies are mostly being tested only, few schools are using the technology on a regular basis (apart from some vocational and higher educational institutions where virtual reality is used for professional training). Even though XR is not widely used in K-12 education at the moment, most respondents see potential in these technologies and are aiming to start adopting them either in the next 12 months or in 2-3 years.

HITSA has recently also started a program for educational innovators, to enhance the use of new technologies in K-12 education by developing meaningful use cases. One section of the program involves XR and during the program, participating teachers are given necessary hardware which they can test and create lesson plans, implementing AR and VR. The outcome of the project will be teachers' feedback of the technologies, lesson plans which will be distributed also among other teachers, as well as practical guidelines how to implement AR and VR the most valuable way for the local school system.

There have been other initiatives for introducing AR and VR to schools as well. For example, in cooperation with Tallinn University's VR lab Medit and Tallinn City Council, 8 K-12 schools in Tallinn opened dedicated technology labs in 2018, one of them for XR.

5.5.2.1.2 Research on XR in Estonia

Several universities in Estonia have established XR labs for carrying out research in various fields. Tallinn University of Technology (TalTech) is running research activities in two labs:

- Re:Creation Lab, focused on research in VR from psychological and physiological aspects, and educational XR solutions for professional training.
- IVAR - Industrial Virtual and Augmented Reality Laboratory is focused on research for industrial solutions. IVAR Lab is also a member of EuroVR association and will host EuroVR conference in Tallinn in October 2019.

Medit Creative Lab in **Tallinn University** is involved in XR solutions for creative industries, including digital media, reusing digital cultural heritage and heritage-based data, development of educational applications that recycle digital heritage content, specializing on 360 videos.

In **University of Tartu**, research activities in XR are carried out from educational, psychological and technological perspectives:

- Institute of Education is working on an international Erasmus + project "EL-STEM: Enlivening STEM Education through Augmented Reality", aiming to motivate students to learn STEM subjects and choose STEM related careers through an approach which connects inquiry learning methodology and AR technology.
- The Computer Graphics and Virtual Reality Lab is carrying out a PhD project testing a computational theory of brain functioning with virtual reality.
- Researchers at iCV Research Lab are working on an Erasmus+ project ViMeLa, creating a VR mechatronic lab environment, enabling students to carry out hands-on lab tests in VR, aiming to improve hard competencies of mechatronics graduates and prepare them for future work by teaching practical skills based on virtual reality. Among other projects, they are also creating an interactive VR shopping mall guide as a part of a Master's thesis, allowing the user to see the fastest routes to specific shops and to browse the building and shops' websites in VR.

5.5.2.1 Latvia

When it comes to XR research activities in Latvia, Vidzeme University of Applied Sciences has established Virtual Reality Technologies Laboratory, whose researchers' work covers numerous fields including medicine, production, architecture, training, tourism, logistics and marketing. The university is also running a Masters program "Virtual Reality and Smart Technologies".

In terms of the adoption of XR in general education, no initiatives were found during this research.

While there are a number of enterprises in Latvia working with XR technologies, one company, Anatomy Next is specifically focusing on educational purposes, which is of interest of this report. More specifically, they are developing Trauma Simulator—a virtual reality emergency training simulator for training medical personnel. The system simulates lifelike emergency room environment with four most common injuries on battlefield, enabling the user to use voice commands and move around the room while providing real time feedback. The simulator also incorporates analytics, enabling to review user's performance on the given tasks.

In addition, Anatomy Next has developed a human anatomy learning application Anatomy Labs for medical training, enabling students to perform dissections and inspect human anatomy in VR. The application also includes knowledge tests to help students prepare for exams.

5.5.2.3 Lithuania

Researchers at **Kaunas University of Technology** (KTU) are working with XR in various fields, including medicine, sports and wellbeing. Some examples of the projects carried out by KTU researchers are as follows:

- **Virtual rowing**: Software transforming natural movements into digital information. By using rowing simulator Concept2 together with VR headset the rower is transferred to Galvė lake in Lithuania. Further developments of the project are allowing its users to participate in competitions. The project has been successfully introduced in a number of fairs in Lithuania and abroad.

- **Diagnostics of vestibular function disorders**: Joint project of KTU and Lithuanian University of Health Sciences (LSMU), aiming to develop a VR system for diagnosing disorders of vestibular apparatus. The project was elected the best joint project of KTU and LSMU in 2016. See more info here.

- **Abili Balance Analyzer**: ABA is a balance testing and training equipment, which can be used both for sports activities in order to train and strengthen the deep muscles of the body, and for rehabilitation after certain illnesses. A person, wearing a VR headset is climbing on the balance platform and participating in a game, which aim is to remain standing on a tree trunk floating in a river. The software is assessing the exactitude of movements, and the player is collecting the points and passing through different levels of the game. The technology makes balance exercises and training more exciting, it helps motivate sportsmen and patients to aim for better results.

- **Paraglider simulator**: Imitating the construction of a paraglider, a team of KTU researchers designed software which simulates a flight above the KTU campus.

- **Skiing simulator**: Software providing a VR experience of skiing, involving feeling of wind gusts and vibration.

Vilnius University has been implementing research results in XR in one of their projects. During an international project "Actualization and presentation of Jewish cultural heritage through mobile application", an AR mobile application Discover Jewish Lithuania was created, offering a guided tour to learn about Jewish cultural heritage in specific locations around Lithuania in AR. In addition to this, a number of students at the Faculty of Mathematics and Computer Science are working on different projects with immersive technologies.

As in Estonia and Latvia, there are numerous companies working with XR technologies, however, few projects are targeted towards educational field. An interesting project to note has been created by an AR/VR agency Inlusion in cooperation with a local school: VR language training simulator for students. The simulator takes students to a 3D modeled apartment where one can move around and interact with their surroundings to learn new words in a foreign language. See more information about the solution here.

6.0 XR-Edu: Key Issues, Opportunities & Challenges

The very recent decision by the Norwegian Prime Minister to create a new Ministry for Digitalization points to the growing recognition that the digital transformation of society—in all sectors—now deserves greater attention and resources in order to be ready for the future, and to actively shape the future. Other Nordic and Baltic countries (such as Finland and Estonia, in particular) may be ahead of Norway in effectively using digital technology. But I think it is fair to say that all Nordic and Baltic countries are still in the early phases of developing comprehensive policies and strategies for edtech, or digital technologies in the education sector. And since XR is a subsector of edtech, we're still in the very early stages of recognizing and deploying XR-Edu. But this also means this is a good time to look for insights gained so far and draw implications for what action steps can be taken, by players and stakeholders in the Nordic & Baltic XR community who have an interest and stake in the future of education and learning.

6.1 Key Issues

Industrial deployments of XR—such as what IKEA, Equinor and Fortum, for example, are demonstrating (including for training)—may be more widespread than Nordic/Baltic XR deployments in the in education sector. But Denmark may soon have projects and pilots illustrating what can be done with Labster's VR platform in a number of universities. More generally, the following issues are facing schools and universities as they are exploring the use of XR:

- *Awareness and Understanding*. Few teachers or even university professors have good awareness of how XR could be used in education and teaching, but the work that HITSA has done in Estonia, with the survey and guide for educators, points the way for others across the region. And research programs such as the one Innokas Network has recently led in Finland, have helped create greater awareness and understanding (and similarly with the earlier FinEduVR iniative), and given some teachers an opportunity to test VR and related technologies (such as 360° video) in teaching. And these kinds of programs give teachers an opportunity to consider how to integrate these technologies into their curriculum. But more must be done in creating lesson plans and also share lessons learned in pilot programs done in other schools.
- *Mindset and Risk Aversion*. Experimentation with new technology, and accepting the risk that not all projects and applications will be successful—and that failure is acceptable—is more common in industry than in most school systems (and in higher education). Much is said about the importance of innovation but most schools and academic institutions typically are not good "risk taking environments." Changing this mindset will not be done over night, and will be a significant future challenge. Meaningful incentives for teachers and professors to experiment and innovate may also be needed to encourage behavior change.
- *Lack of Training*. Most Nordic and Baltic countries are known for having extensive and high quality teacher training colleges or programs, but most of them have been relatively slow in including digital tools and technology. And since XR technologies are still seen by many as being more "leading or even bleeding edge" technologies, they are even further behind other, more "mainstream" digital technologies to be included in teachers' digital technology training.
- *Cost & Funding*. Little information is yet available to make clear to school administrators and other education policy makers what the total costs would be involved for deploying XR technologies in schools. In industry, new technology deployments are typically started after "return-on-investment" (ROI) estimates have been made, to justify their investments, but calculations for XR-Edu are likely to be even more tricky than in industry because the difficulty to quantify the improvement in learning outcomes due to the use of the new technology.

6.2 Major Opportunities

As noted above, a growing number of industrial companies are already recognizing potential opportunities for improving their business processes and by doing things more efficiently and effectively, lowering costs and improving business performance results. In his presentation to the Chalmers VR Conference in Stockholm in 2017, IKEA's Martin Enthed (Digital Lab Manager) gave a presentation on "IKEA VR, AR, MR and Meatballs." In his presentation he noted that they estimate to save around $1 million over 5 years from using VR. He also noted that they are expecting to also use VR in their training operations, and that the sales division of IKEA saw significant opportunities in using VR as a way to improve their training operations.

In education, as noted in the previous section, the willingness to innovate and take risk with new technology typically is less than in industry, so "the Martin Entheds" in education are likely to be fewer

than in industry. But many projects have been done and are under way in various schools in the US (see Box F that described the projects of Foundry10), Scotland, Germany as well as smaller projects done in Finland and Norway discussed briefly earlier in this report. From these and other projects, these are some of the opportunities that now exist in Edu in coming years:

- *Improving Learning Outcomes*[38]. This is the "bottom line impact" that businesses require, and once schools and universities can show improved learning outcome—already shown in a number of academic studies (see References section of this report). Having strong "evidence-based research" to use with educational policy makers, and thus demonstrating clear "Return-on-investment" (ROI), will make it easier to get local/municipal, provincial and national educational policymakers agree to make the needed investments in equipment, XR content, and training for teachers. As we have shown in this report, there are plenty of academic research centers and institutes in the Nordic & Baltic countries that can work with schools during XR pilot studies to collect the right student outcome data and demonstrate the impact of the new technology. And since educational policy makers, including in education ministries, are now becoming more understanding and supportive of edtech in general, the time is also right to start building support for use of XR, or "next-generation edtech."
- *Raise Student Engagement*. It is well-known that typical and traditional lecture-based teaching leaves a great many/most students bored and unengaged in the learning process. And immersive technologies, such as virtual worlds and XR have the potential to significantly improve engagement. Immersive learning can take us from "book learning" to "active learning" where students apply principles and "learn-by-doing" which is aligned with the growing "maker movement" that has gained growing popularity, especially in the US. This form of active learning is finding growing use in both classrooms and other learning spaces, such as community libraries and other emerging places[39] where students are now learning about coding for immersive environments. Figure 9 illustrates the factors that can affect learning engagement.
- *Raising Interest in Coding with XR Connection*. Students can learn with XR without coding and creating immersive environments, but especially high school and university students with interest in computer science and coding would find opportunities to learn coding that would help create immersive environments in which they, and fellow students, could then interact with 3D models. Finland, Denmark and Estonia have been leaders in introducing coding in schools as part of embracing 21st century education, but other Nordic countries are now following suit and will likely see greater focus on this in coming years.
- *Building Unique Nordic XR Learning Content*. Most of XR technology should probably be left to much larger players in the US, China and major EU players that have needed resources to play the HW game (although small Nordic/Baltic players[40] with unique Intellectual Property and competence may target niche market segments). However, on the content side, smaller players could develop unique XR content that would enable high quality learning experiences (in the same way that Snorri Þór Tryggvason has done with high quality 360° video content leveraging the unique natural beauty of Iceland). Would not high school students around the world—and perhaps even university students—find strong appeal in being able to experience, immersively

[38] In Norwegian pilot programs run by VR Education (a Norwegian startup company), early indications are that students are learning math much quicker and more effectively by using VR, in part because they experience less distraction around them (from fellow students, social media, etc) during the learning process, as the VR headset "removes outside distractions."

[39] Such as the Immersive Learning Center in Vallejo, California. See here.

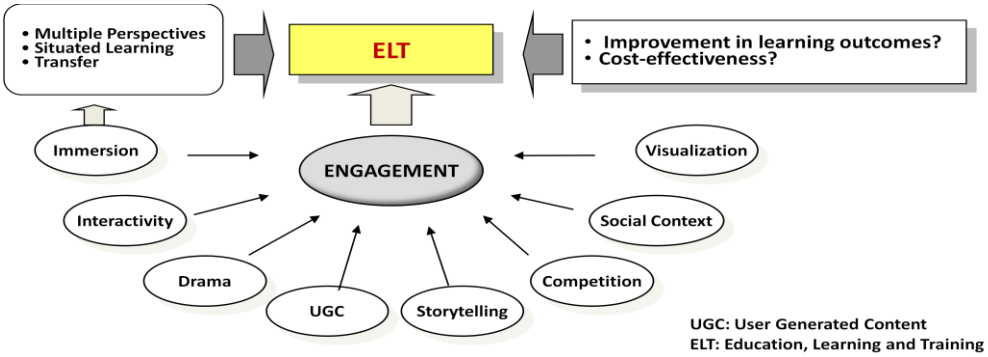
[40] For instance, Varjo—based in Helsinki—last year gained considerable attention worldwide, when it raised $31 million in late 2018.

the trip across the Atlantic with a bunch of Vikings, to really gain a deep appreciation of what those trips were like? This would no doubt be a totally different experience than reading in books about the Vikings and Vikings ships. Lots of content could be done that would leverage rich historical and cultural heritage materials that today sit (mostly in static resources) in museums and other venues around the Nordics. Of course, a growing number of projects have been done or are now underway to leverage such resources, as we saw in the sections on Finland as well as the Baltics, for instance.

- *Collaborate and Create Nordic XR Brand*. Each of the Nordic and Baltic countries are small—with the exception of Sweden with about 10 million people, all the others are half that size or quite a bit smaller. Why not leverage Nordic & Baltic collaboration—and seeking financial support from Nordic and Baltic funding agencies (such as Nordic Innovation) that seek to help build "Nordic Champions" that can leverage the Nordic brand in international markets. Now, as XR is just in its early phase of development, especially with respect to XR-Edu, this would give the region time to jointly build strong XR learning programs that would be ready for world markets when schools and universities would be ready for it. Labster has already made great progress in leveraging its strong online/virtual science education platform, and has gained an impressive list of university clients around the world. Nordic and Baltic collaboration, in part by leveraging R&D currently under way in many of the region's academic labs, could mean that in the next 5-10 years, the region could see many more "XR-focused Labsters" with unique XR offerings in specific market segments where these players could become "world champions" (and perhaps in technical or distribution) partnerships with larger US, Asian or European players.

Figure 9

Learning Engagement in Immersive Environments



Source: Eilif Trondsen, Silicon Vikings

6.3 Key Challenges

To a large extent, the challenges ahead—especially in the next 2-3 years (and uncertainty is too great to look much further out)—will depend on "where you sit" or "what hat you wear." Below, I have summarized some of the key challenges that I see for five major categories of stakeholders in XR-Edu. Some of these challenges may also have relevance and implications for other stakeholders of the XR ecosystems in the Nordic and Baltic countries, such as investors (VCs or angel investors) considering whether Nordic and Baltic XR startup companies focusing on Edu might be good investments.

6.3.1 Educational Policymakers

The "bottom line" for most educational policymakers are to ensure the best educational outcomes for students while living within the educational budges they must operate within, while simultaneously keeping "all the troops" (everyone working in educational institutions) as happy and fulfilled as possible. For the purpose of XR-Edu, some of the main challenges they will likely face, include:

- *Low priority for XR technologies*. Most policymakers are just now becoming sufficiently familiar with more "mainstream" edtech technologies, and will not yet be sufficiently knowledgeable about XR to make deployment decisions. But depending on the briefing materials they have received, they may be willing to support more research and/or smaller pilot studies to gain data on what impact these technologies will likely have in different learning situations.
- *Small number of XR lobbyists*. The number of supporters and lobbyists to argue the case for XR-Edu is still quite small. The Nordic and Baltic edtech ecosystem has gained strength and numbers of participants over the last 2-3 years and have succeeded in building greater understanding and support for edtech at different levels of government, but for XR the numbers are still low.
- *Uncertain cost-benefit analysis*. Just like CEOs and CFOs in enterprises will ask for ROI and cost-benefit analysis evidence that demonstrates the expected value of a new technology, these numbers are still missing, in most cases, for XR-Edu deployments. This is a major gap that needs to be addressed in coming years. XR supporters in the Nordics and Baltics need to gather studies that have been made and launch their own, local pilot studies that yield data needed for such ROI/cost-benefit metrics that policymakers will likely ask for.[41]

6.3.2 School and University Administrators

These individuals are typically a number of "layers" below the policymakers, so they must live within the context that the policymakers set. In most countries, the guidelines they must follow typically don't change very much from one year to the next, except when a new government comes to power and wants to change past policies, to reflect their own "world views". For instance, the new situation in Norway, with its first majority right wing conservative government since 1985, and especially with a new Minister for Digitization, significant new policies may come that may bring policies that are more pro-technology in schools. But the Minister of Digitization, Nikolai Austrup, must work closely with and collaborate with the two Education Ministers, Jan Tore Sanner (Minister of Education and Integration) and Iselin Nybø (Minister for Science and Higher Education). It is too early to know how this collaboration will work out and to what extent they will agree on the future role of tech in K12 schools and universities.

- *Insufficient comfort level with XR*. In the Nordics and Baltics, XR technologies in schools and higher education have come on the scene only in the last few years. Even if other institutions in

[41] A large share of the whitepapers and academic studies focused on XR-Edu so far seem to be in the science education area, and not surprisingly Labster has been active in encouraging such studies (see Reference section—8.0)

the US and other countries have more experience with XR in education, most school and university administrators in the Nordics and Baltics are unlikely to know about these deployments. This may change in the next 2-3 years, but their comfort level will take time to change quickly.

- *Sufficient demand from teachers?* Some teachers and professors, and especially "change leaders" and the likely "innovators" that exist in many schools may already be starting to lobby their principals and school/university administrators for funds to test XR in some small pilots. But again, this kind of "push from below" is likely only now starting, based on evidence I have seen so far, although XR researchers in university labs will continue their "new knowledge pursuits" and will likely seek, and hopefully gain, funding for a variety of XR projects that involve pilot studies of "XR-Edu in action."
- *Funding priorities and impact uncertainties*. Schools and universities are typically quite resource constrained, and while costs of many types of XR equipment and content are becoming more affordable, costs will likely still be of concern. This is particularly true when adding costs of hardware (headsets), computers, content and labor time (or professors and support team). The result may be situations such as found in the Finnish VISIOT project where one headset had to be shared among all the students in the pilot.

6.3.3 Teachers/Professors

Without good awareness and understanding of XR and its potential role in education, and having sufficient comfort in how they can take advantage of XR in the classroom—in a way that improves student engagement and learning outcome—teachers and professors may not be convinced to use these new technologies. Those proposing the use of XR must therefore work to ensure that these potential obstacles are addressed so that teachers and professors see strong benefits without facing major implementation challenges. More specifically, here are some of the major challenges they may raise to the use of XR:

- *Time investment*. Many pilot studies find that teachers often invest much of their spare time in these projects and often don't have the level of (technical) support they should ideally have. And since teachers are typically short of time even before experimental XR deployments are launched, time often becomes a major challenge facing those involved in these kinds of projects.
- *Risk and uncertainty*. As noted earlier, most schools and universities are not known for encouraging experimentation and innovation, and embracing risk. In fact, most go in the opposite direction, to discourage risk taking to avoid "hurting students" with projects that fail! This attitude puts a major break on those interested in being innovative and testing new technologies.
- *Uncertain learning impact*. Teachers are likely to know how students often are excited about using XR, in part because it is "fun." (i.e. much of this might be "novelty factor" and it is unclear how long this lasts). Teachers and professors are also likely to know about the "engagement" impact, but what this means for learning outcomes is where more solid data are needed.

6.3.4 XR Edupreneurs

While teachers and professor are on the "demand/buying side of the XR equation," XR Edupreneurs are on the "supply side" and must work to provide the best solution at the lowest price in order to gain adoption. As for other entrepreneurs in startups in other industry verticals, the XR Edupreneurs needs to have deep understanding of the "market friction", i.e, the problem that the XR solution will solve, and

convince the buyer(s) that his/her solution will indeed do the trick and also be as simple to implement and use as possible. Some of the major challenges they will face include:

- *Resource constraints*. Most edtech startups are very resource constrained, yet should spend a lot of time and resources into product/service testing and retesting and constant product adjustment in view of user feedback. A recent article[42] described this challenge and how a US edupreneuring company with a VR solution "embarked on its first national pilot program for BioDive, a game that uses an online journal and VR immersions to simulate the experience of marine biologists on underwater missions."
- *Finding customers and running pilot studies*. XR Edupreneurs need to persuade teachers (and perhaps school principals) to join a pilot studies, administer the studies efficiently and effectively (ideally with participating academic researchers), and then convince potential customers that the improved learning outcomes (and engaged students) are worth the new investments that are needed.
- *Successfully persuade investors and grant agencies*. Ideally, funding needed investment from internal growth and recurring revenues is a great way to avoid VCs who may have very different visions and timelines from the founders. In the Nordics and Baltics national grant agencies have become more generous in funding early stage edtech (and other) companies with at least some of the funding they need. Overcoming the challenge of convincing them that the company is worth grant money, is thus an important XR edupreneur milestone that must be met.

6.3.5 XR Researchers

This is likely to be a diverse group of stakeholders, but I will focus on those who work in academic or company-owned XR labs, so they may be in private or public institutions, and thus may have different funding sources. Those in company R&D labs will be working on funding that comes from recurring revenues or investor funding, while researchers in academic labs may get most funding from public grant sources, or perhaps from corporations sponsoring some or all of the research. These are some of the major challenges these XR ecosystem stakeholders will likely face:

- *Gain research funding*. This is the "fuel" that enables high quality research to happen. Writing excellent proposals that promise innovative/path-breaking research is also what helps recruit strong team members into the lab and also helps entice other researchers, from other institutions in other countries, to join a project and thus helps ensure excellent research outcomes.
- *Build strong research teams or consortia*. Increasingly, virtual research consortia and teams bring together colleagues who have similar interests and whose reputations are such that their participation in a research proposal team makes winning more likely. Ideally, in XR-Edu, XR Edupreneurs are part of some of these research projects and may also invite academic researchers into their pilot projects to validate pilot design, data collection procedures and help doing data analytics to evaluate technology impact on learning outcome.
- *Publish and build strong connections and alliances with XR community*. A combination of theoretical and applied research, combined with published articles and reports that share findings with the larger regional or global XR-Edu community, will bring strong benefits to all stakeholders in the Nordic and Baltic XR-Edu community.

[42] "This Educational Gaming Company Has Testing Down to a Science"; https://bloom.bg/2B9dJxV

7.0 Future Perspectives

Digital transformation—driven by a range of tools and technologies, such as Artificial Intelligence, robotics, 5G wireless networks, Blockchain, etc.—has for a number of years been building momentum across most industries and sectors, and in all developed countries. And global tech giants have bold plans and hopes for XR, including Facebook which seems intent on making VR a mass market force on its own platform. Facebook CEO, Mark Zuckerberg, has made it clear that his goal is to eventually bring 1 billion people into VR. The timing around this is of course uncertain, but if and when it happens, it will create a new and very different context for XR-Edu.

In the last few years, one interesting element of digital transformation in manufacturing that was referred to earlier in this report is that many companies (such as Kongsberg Group in Norway, for instance) are now building "digital twins" of their products, in part so companies can run simulations and test the products under different scenarios. The result is that more companies will now have 3D models of their products, which can then be used for XR training—of employees in manufacturing or in sales, for instance. A much longer-term and much more transformative "digital twin" concept—one that would create a digital copy of the real world--is what "AR Cloud" (referred to as the "world's digital twin") initiative would bring about. According to the Founder and CEO of Augmented World Expo, Ori Inbar, "the AR Cloud will be the single most important software infrastructure in computing, far more valuable than Facebook's social graph or Google's page rank index."[43]

3D models are also becoming more commonly used in a range of other industries, including Architecture, Engineering and Construction (AEC), and companies like Autodesk and other digital design tool companies are contributing to this development, as they are creating new tools and technologies that companies in AEC sectors and others can use in part to make their operations more cost effective. This development in turn is also creating the foundation for greater use of XR technologies, as more 3D models will exist that can be used in XR, or modified to find use in XR applications.

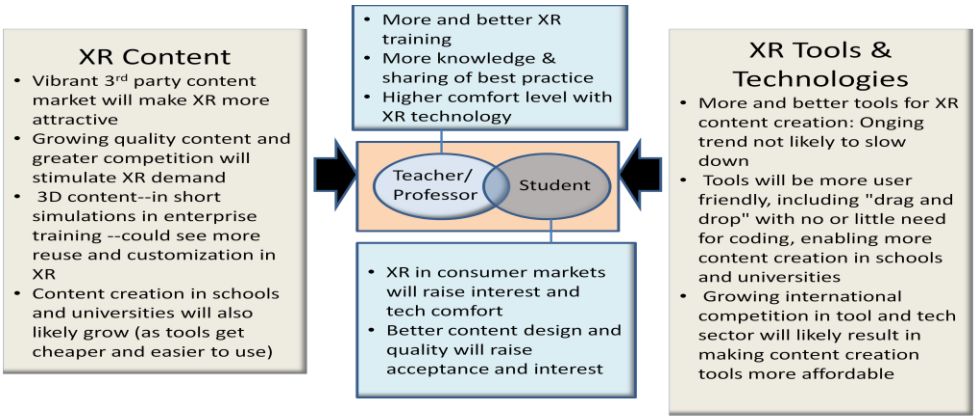
Digital transformation and the use of 3D models in the education sector lag that of most other sectors, but digital tools are seeing growing use. And with growing interest by government policy makers, and growing activity in this area by industry, greater cooperation and collaboration between schools, universities and the enterprise sector—to improve workplace readiness by students and for them to understand what is happening in the workplace of the future (and the role of digital technology)—interesting opportunities lie ahead.

While XR will most likely see slower adoption in education sector than in industry (for a variety of reasons discussed earlier), change is coming, particularly as the benefits of these new technologies become more evident (as is happening in both manufacturing and the health care industry, for instance). As we have seen in this report, a number of explorative XR-Edu projects have already been done, in Finland, Norway, Estonia, and others are under way in Demark—among others. And more activity will likely be seen in the next few years. Figure 9 provides a summary of some of the factors that will affect future XR-Edu adoption.

[43] https://zd.net/2JiRbB4 The Norwegian University for Science and Technology and Norkart (a Norwegian company focused on developing geographic information systems and data https://www.norkart.no/)

Figure 10

Factors Shaping XR Adoption in Education



Source: Eilif Trondsen, Silicon Vikings

7.1 Nordic/Baltic Ecosystem Collaboration in XR-Edu

I noted earlier how the Nordic/Baltic edtech industry has gained momentum in recent years, and the opportunity now exists for the region to shape a similar development for XR-Edu as a very interesting and emergent subsector of edtech. Such a development could be stimulated in part by "connecting the XR dots" across the Nordic/Baltic region. This would leverage various strengths that exist in academic labs, many of which have been identified in this report, as well as companies and a variety of XR ecosystem players that could help build a strong XR-Edu industry in the Nordics/Baltics.

In a similar way to how the very successful, Norwegian edtech company Kahoot!—currently with 50 million unique users per month, 80% of which are in North America—took advantage of academic expertise at NTNU, through the role played in the company's early development by Professor and Inventor, Alf Inge Wang, future XR-Edu companies could also take advantage of both human expertise, policy support, and other resources that exist across the region.

On possible scenario of collaboration and leveraging existing institutions are illustrated in Figure 10, which has the following four main components:

- **Joint Nordic/Baltic XR-Edu Research Lab**. This would be a small lab that would focus on deployment of XR technologies in educational institutions. I could see such a lab consisting of 2 parts: One focusing on schools, and one on universities—and each of them could have 3 staff members, One technologist, one pedagogist (focusing on how XR technologies can best improve learning and teaching processes and learning outcomes), and one "knowledge curator" whose job

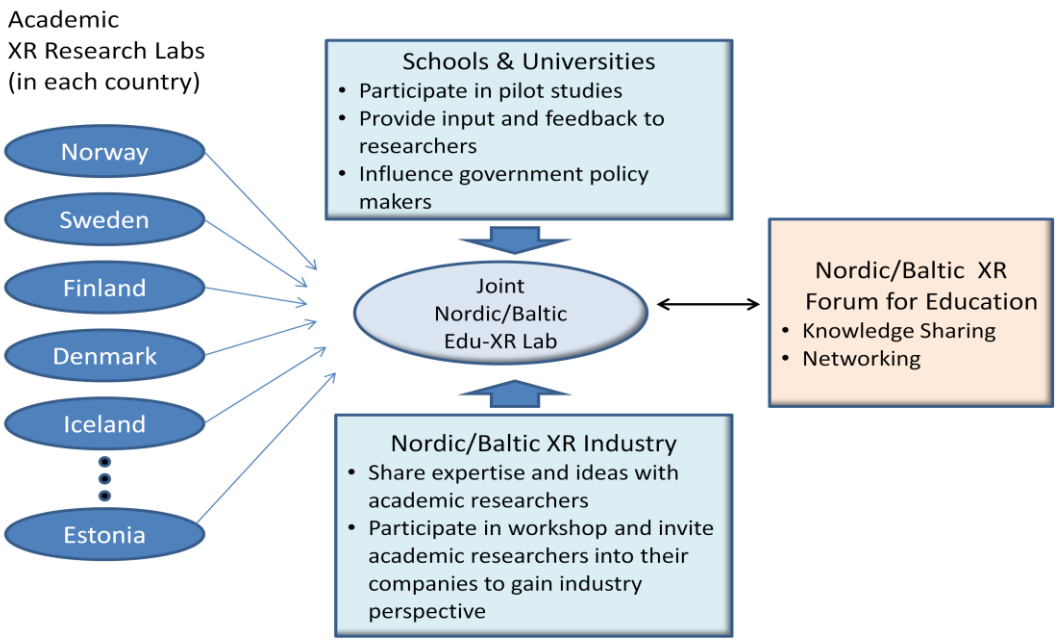
it would be to identify and curate XR-Edu reports and papers (from around the world) that would be relevant for the lab and its stakeholders. The lab therefore would not address more "basic research" issues and topics that existing academic labs would likely include in their research portfolio. The joint Nordic/Baltic XR-Edu lab would ideally be jointly funded by a number of funding agencies from the Nordic/Baltic countries. The idea is also to draw on, leverage and build on the XR research that has the greatest relevance for deployment of XR technologies in schools and universities.

- **Schools and universities as active participants in lab**. Schools and universities would be major beneficiaries from the highly applied research focused on deployment of XR technology, but to gain the most benefit, these schools and universities should be deeply engaged with the XR lab, especially through pilot studies (and as needed, the XR-Edu lab would draw on academic researchers around the region). Schools and universities and their staff would have the greatest "on-the-ground" experience with students and curriculum, and thus would be able to provide great input and expertise that should help the XR-Edu Lab's staff.
- **XR companies and other ecosystems players providing input into lab**. In many ways, companies that are part of the XR ecosystem should provide similar input and benefit from XR-Edu labs activities in the same ways as schools and universities. The two-way exchange of expertise and strong dialog should benefit both lab and the companies, and help the latter design better offerings, including content, for educational institutions and their students. A similar institutional setup was created last year for edtech in Finland, where academic labs and researchers serve as intermediary agents to help ensure better edtech products that meet real educational and student needs are created[44].
- **A new Nordic XR-Edu Forum**. The final element is to create a public Forum that could bring especially teachers and professors—but also other players in the XR-Edu ecosystem—together to share information and experiences. This will avoid "reinventing the wheel" around XR solutions for schools and universities, including drawing on lessons and best practices from outside the Nordic and Baltic region (which the "Knowledge Curators" of the XR-Edu lab would bring about). This kind of Forum could perhaps be connected to the already existing Nordic VR Forum that the Hamar XR community has established.

Figure 11

Institutional XR-Edu Ecosystem Perspective

[44] The project, Inno-Oppiva, or Co-Development of Educational Technology is led by Professor Jarmo Viteli at Tampere Research Center for Information Technology and Media (TRIM



Source: Eilif Trondsen, Silicon Vikings

Box K

VR First: Industry Collaboration With Academic VR Labs

In some ways, VR First—founded early 2016 and located in Luxembourg—is promoting and helping accelerate education of VR developers (and "democratizing VR Innovation") in the way EON Reality has been doing, particularly by collaborating with academic institutions around the world. VR First set a goal of having 50 VR First educational labs at universities by the end of 2017. It now reports having a total of 52 such labs: 24 in Europe (including Aalborg University and Tallinn University of Technology, School of Information Technology in the Nordics/Baltics) , 13 in North America, 4 in Latin America, 8 in Asia, 2 in Australia and 1 in Africa. A number of Network Partners—including VR/AR Association, Institute of Electrical and Electronic Engineers (IEEE)[45], International Association of Science Parks and Areas of Innovation, and World Business Angels Investment Forum—have provided help and assistance in finding academic institutions and in building labs around the world. Industry Partners of VR First include HTC Vive, VRMark, Leap Motion and others.

VR First, which Crytek (the Germany-based VR and game engine maker, ranked as number two among the most popular gaming engines, after Unity) helped start, sees four phases to the establishment and success of the educational VR labs:

[45] Through its Lab Renovation Program, VR First will work with IEEE standards groups (including the IEEE Digital Senses Initiative) to promote the adoption of new standards by lab partners, governments, and science parks.

- *Lab Seed Support*. Academic institutions that want to work with VR First apply for support to establish a VR lab or Center. This includes state-of-the-art hardware and software as well as a global communications platform.
- *Regional Growth Services*. The new labs have access to a range of services for building their XR facilities, including help in designing customized VR environments. VR First also provides its labs with lab renovation issues as well as with equipment solutions.
- *Mentorship Program*. The labs share expertise or get feedback via a mentorship program that VR First has established. The VR First network has industry experts working at HP, HTC, MetaVRse and other VR/AR companies that can serve as mentors and help lab projects get to the next level.
- *Enablers of Tomorrow's Network*. The labs link their local VR/AR network with the global community and VR First Evangelists and Pioneers proactively engage their local communities by organizing events, growing their networks, connecting them globally and getting local support from the global VR First Partners.

In 2017, VR First reported that "Games account for about 35 percent of the projects underway, and 12 percent are focused on psychology and neuroscience, 7 percent on education, 7 percent on tourism, and 6 percent on architecture and real estate, among other verticals." It also noted that 48% of the labs had Unity as the preferred engine, followed by Unreal (20%) and CryEngine (14%). The data may be somewhat different today, but may not be radically different from those reported two years ago.

7.2 Recommendations For Building Vibrant Nordic/Baltic XR-Edu Future

Specific action steps must be viewed from the perspective of "where you sit" (or "what hat you wear") but here are some generally accepted goals for education, learning and training, which we should keep in mind when thinking about future actionable steps"

- Learning should be as "student-centered and student-driven" as possible. Some would refer to this as "customized learning" as it would meet a specific student need as much as possible.
- Learning should ideally be adaptive[46]. This means the "learning journey" should consider, at every step of the way, what the student/learner's context is, i.e. adjusting the learning process to meet the "student where he/she is at," to ensure the right level of challenge that a student can handle.
- Ideally, make the learning engaging and interesting, as growing evidence points to things like "game-based" learning providing incentives and a bit of fun, can keep the student engaged and interested, and thus helping improve the learning outcome.
- The learning process could be improved if data could be collected throughout the learning journey, enabling "continuous assessment" of how much is learned, what factors are contributing to the most effective learning. And the learner data should be "owned" by the learner.

There is growing evidence that XR technology can help achieve many or perhaps most of these goals, and likely others, and thus should be the focus of future research and especially pilot tests that put the

[46] Here are two short articles on what Arizona State University are doing with Adaptive Learning: (1) Arizona State Accelerates Progress With Adaptive Active Course (https://bit.ly/2WAPNvP) and (2) ASU leads the charge for adaptive education (https://bit.ly/2FCMXzc)

technology through the paces in actual learning environments in schools and universities and with a great variety of students, most of whom have different needs.

The overarching recommendation is to give these emerging technologies a chance to prove themselves "in the field" and also be given resources to be developed further, as the underlying enabling technologies are still developing. And a wide range of XR content is needed to make the learning experiences compelling as well as improving learning outcomes.

The Nordic/Baltic region already has a strong global brand in the field of education and learning, and as we move further into the digital era, we must take full advantage of emerging technologies that could enable "next-generation learning." As digital transformation accelerates, old ways of learning will unlikely be able to meet needs in a time of exponential change—whether one is in an educational institution or needing to learn new things in the workplace. The time for bold action is here, and the time is right for strong action.

8.0 Selected XR References[47]

A. Global XR: General

Damian, Jesse ; How China's Largest VR Community, VRCORE, Is Bridging Eastern And Western XR Markets; December, 2019

Fink, Charlie--Guest Post by Dr. Annika Steiber; Will China Be The Winner in VR/AR? December, 2017

Fink, Charlie--Guest Post by Dr. Annika Steiber; VR/AR in China: An Emerging Giant? December 2017

B. Global XR-Edu

Bache, Iben; Bonde, Mads T.; Creed, Peter A.; Hood, Michelle; Makransky, Guido; Nørremølle, Anne; Silahtaroglu, Asli; Wandall, Jakob; Wulff, Julie S. G.; Simulation based virtual learning environment in medical genetics counseling: an example of bridging the gap between theory and practice in medical education; BMC Medical Education; March 2016

Ergurel, Deniz; These global research ceners are more proof that virtual reality if more than giving; Haptic.AL; August 2016

Evangelista, Benny; Universities dive into VR research; SF Gate; March 2017

Georgieva, Maya; Mixed Reality Will Transform Learning (and Magic Leap Joins Act One); EdSurge; July 2018

Langston, Jennifer; UW Reality Lab launches with $6 million from tech companies to advance augmented and virtual reality research; University of Washington News; January 2018

Loewus, Liana; How Virtual Reality Is Helping Train New Teachers; Education Week; September, 2017

[47] References not already provided in report footnotes and hyperlinks

Ramsey, Doug; Giving Students a Place to Prep for Tomorrow's Virtual (Reality) Economy; UC San Diego News; May, 2017

Ramsey, Doug; UC San Diego and edX Offer Professional Virtual Reality Courses Online; UC San Diego News; April 2017

Takahashi, Dean; Hundreds of universities want to teach VR development, but few have the equipment; VentureBeat.com; August 2016

Takahashi, Dean; VR First is creating 50 labs for virtual reality education at universities; VentureBeat.com; April 2017

Walsh, Kelly; Real Uses of Virtual Reality in Education: How Schools are Using VR; EmergingEdTech; June 2017

9.0 Brief Author Bio

Eilif Trondsen, Ph.D. is former Research Director at Strategic Business Insights (SBI) in Menlo Park, California. Currently, he is spending most time on pro bono work for edtech startup advisory boards, and serving on the Board and Executive Committee of Silicon Vikings. Eilif has also served as Chair of the Special Interest Group on Innovation, Entrepreneurship and Learning of Silicon Vikings from its launch in 2012.The focus area of his research and consulting at SBI—a spin-out of SRI International (formerly Stanford Research Institute)—has been on the use of technology for innovation, education, learning and performance improvement. He has 40 years' experience at SBI and at SRI International, leading or contributing to a variety of projects for U.S. and foreign clients in the private and public sectors. At SRI and SBI, Eilif held the positions of Research Director of the Business Intelligence Program (now the Scan program), Director of the Learning on Demand (LoD) program (exploring the role of technology in learning and training), and has also led SBI's research initiative around 3D immersive technologies (Virtual Worlds @Work). In his tenure at SRI and SBI, he has given numerous presentations on various eCommerce, eLearning, Silicon Valley innovation topics and developments, as well as virtual-worlds topics at conferences and to SRI clients around the world. He is the author and co-author of numerous publications and social media posts on eCommerce, eLearning and Silicon Valley innovation trends and issues. Eilif's current work is focused on helping connect the Nordic/Baltic region to Silicon Valley and focusing on Nordic and Baltic edtech issues and developments. Prior to moving on to the world of AR and VR, and how these emerging technologies will affect future education, learning and training, Eilif led a Nordic EdTech Network project, a Silicon-Vikings-led initiative, funded by Nordic Innovation (HQ in Oslo, Norway). The project identified, profiled, and evaluated Nordic edtech companies and mapped the industry and its dynamics. The project helped stimulate a Nordic edtech community through face-to-face and online/virtual platforms and events, working collaboratively with a range of Nordic edtech ecosystem catalyst organizations (see http://net.futurelearninglab.org/). He hopes that his currernt AR and VR work may stimulate similar cross-regional collaboration and coordination in the Nordics/Baltics as was seen in edtech in the last 3-5 years. Eilif can be reached at eilif.trondsen@siliconvikings.com