TechTrends (2024) 68:295–306
https://doi.org/10.1007/s11528-023-00925-y

ORIGINAL PAPER

Towards a Framework for a Nation-Wide Implementation of Augmented, Virtual and Mixed Reality in K-12 Technical and Vocational Education

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Accepted: 7 December 2023 / Published online: 23 December 2023

Abstract
As augmented, virtual and mixed reality have become more user-friendly and affordable, these technologies gained increasing interest from education. Teachers all over the world are triggered by the perceived benefits and start experimenting. However, teachers encounter obstacles to pursue effective implementation. This paper describes how these obstacles are being tackled in Flanders (Belgium) via a large-scale, nation-wide framework for the implementation of augmented, virtual and mixed reality in K-12 technical and vocational education. This framework was designed, adopting an Educational Design Research approach, and consists of five interrelated pillars: hardware, software, professional development of teachers, practice-oriented research, and coordination. The proposed framework provides guidelines, both for researchers and education policy makers.

Keywords Design research · Educational technology · Extended reality · Guidelines · National program · Policy

Introduction

In 2021 the European Labour Authority (ELA) published its annual report on labor shortages and surpluses (McGrath, 2021). One of the key findings indicated a prominent shortage of healthcare and STEM occupations (McGrath, 2021). Similar results can be noticed in the United States with labor shortage most notable in education and health services, professional and business service, trade and leisure and hospitality (Ferguson, 2023). As this is a global problem, furthered by the Covid19 pandemic (OECD, 2023), several initiatives are taken to address this problem of labor shortages.

One of these programs is *The Reskilling Revolution*, launched by World Economic Forum (WEF) in 2020 (World Economic Forum, 2023). According to WEF, 1.1 billion people are liable to be "radically transformed" by technology in the coming years (World Economic Forum, 2023). As such *The Reskilling Revolution* aims to support business, organizations and others, to work together towards better education securing tomorrow's global wealth. This *Reskilling Revolution* is operationalized in a report called *Catalysing Education 4.0. Investing in the Future of Learning for a Human-Centric Recovery* (World Economic Forum, 2022). This framework focusses on four content elements: global citizenship skills, innovation and creativity skills, technology skills, and interpersonal skills. Building on recommendations to harness technology to support life-long learning, as developed by the International Labour Organization (ILO, 2021), WEF suggests extended reality (XR) as one of the technologies which could help to improve educational practices, as it holds several benefits with educational, economic and financial returns (World Economic Forum, 2022, p. 19).

Extended reality (XR) is an umbrella term, including augmented, virtual and mixed reality (European Commission et al., 2023, p. 2) and refers to what Milgram and Kishino (1994, p. 2) indicated earlier as the "virtuality continuum". Augmented reality (AR) refers to a technology which presents the user with a digital overlay over the real world (Akçayır & Akçayır, 2017). Pokémon Go (Niantic, 2018)

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is probably the best-known example of AR. Mixed reality (MR) is very similar as it too puts a digital overlay over the actual environment, but now the digital and physical world interact with each other (Maas & Hughes, 2020). Manufacturing operators from Airbus use MR to assist them during their maintenance procedures, as the digital instructions or parts are mapped onto the objects in the real, physical world (Microsoft, 2019). Virtual reality (VR) finally, immerses the user in a fully virtual world, without any connection to the real world (Luo et al., 2021). Students can for example perform experiments in a virtual chemistry lab, without an actual counterpart in the physical world (Mayer et al., 2022).

The suggestion by the WEF (2022) to use XR technologies as they hold several benefits for education, is supported by research on extended reality in education.

Research on Extended Reality in Education

There is ample research on XR in education, of which the results have been collated in recent review studies and meta-analyses. As the current study focusses on K-12 education, we narrow down our literature overview likewise, which however is less comprehensive due to a scarcity of research on XR in K-12 education (Hamilton et al., 2021; Luo et al., 2021; Maas & Hughes, 2020). Maas and Hughes (2020) found XR learning environments had a positive effect on students' attitude towards learning, and on their motivation and learning outcomes. Similar results were found for AR (Akçayır & Akçayır, 2017) and for immersive virtual reality (Di Natale et al., 2020; Hamilton et al., 2021). A small effect size of virtual reality was identified by Wu et al. (2020), especially for STEM-education and for simulation learning experiences. Luo et al. (2021) found in their meta-analysis that VR technology had a medium effect size on learning, moderated by discipline, level of immersion and instructional design. These results were endorsed by Cao and Hsu (2022) adding sample size and experimental period as significant moderators. A similar medium effect size was found in the meta-analysis on AR education by Li et al. (2021).

Apart from these quantitative results, several other opportunities have been identified, generally labeled as 'learning affordances' (Dalgarno & Lee, 2010; Shin, 2017). Examples are: lower costs, learning and training unlimited by time or space, a high level of interactivity and reducing risks of injury or damage (Cao & Hsu, 2022; Di Natale et al., 2020; Kaplan et al., 2021; Kavanagh et al., 2017), simulating what is in real life not feasible or too dangerous (Kavanagh et al., 2017; Di Natale et al., 2020) and enhanced visual representation of the learning content (di Natale et al., 2020).

These benefits did not go unnoticed by teachers worldwide and XR is now increasingly being used in education (Hamilton et al., 2021). Also in Flanders, a growing series of studies and experiments have been initiated.

Extended Reality in K-12 Technical and Vocational Education in Flanders

The challenges indicated by ELA and WEF, are mirrored in the labor shortages in Flanders. There is a lack of technically skilled people, such as healthcare professionals, maintenance operators and installation technicians (VDAB, 2023).

In addition, students from low-income families or from vulnerable socio-economic status, often opt for technical and vocational education (OnderwijsVlaanderen, 2023a), causing a negative image of low aspiration for the future in other parents, which has been a topic of interest by the Ministry of Education since nearly a decade (Vlaams Parlement, 2014).

This explains the strategies adopted since 2005, by the Flemish Department of Education by installing five network organizations, Regional Technical Centers (RTC). These centers bridge technical and vocational education with industry (OnderwijsVlaanderen, 2019) and support schools in providing professional development initiatives for teachers, renting specific industry equipment and machinery, and lobbying with the industry sector organizations for internship vacancies, funding innovation projects and so on. Other policy actions have been initiated, such as the STEM academies, workplace learning (Vlaams Parlement, 2014) and since 2019 the *InnoVET* program (OnderwijsVlaanderen, 2023b).

InnoVET stands for Innovation in vocational Education and Training (VET) and fosters innovative approaches to tackle challenges in vocational education. Within the context of the *InnoVET* program several XR projects have been realized. Some examples are a mixed reality application to train vocational students how to perform maintenance for hybrid and electric cars, mechanical engineering via immersive virtual reality and an immersive virtual reality serious game training technical students on hazard perception on a construction site. All *InnoVET* projects using XR, foster the educational affordances of XR technologies: providing ample learning opportunities not limited in time, budget, materials and carrying out procedures which would be too difficult, too dangerous or even impossible in real life.

Innovation with XR for education was furthered in the XR Learning Network, which was established in 2020. Its goal was to involve teachers together in a community of practice. Webinars were organized to provide them with essential information on the XR continuum, XR hardware, XR applications which can be useful for education, some XR best practices and finally some didactic tips stemming from pedagogical models such as SAMR (Puentedura, 2006) and T-Pack (Mishra & Koehler, 2006). Finally, 10 schools were involved in a six-month professional development initiative to implement XR technology in the classroom. During and after this period, several moments of exchanging lessons learned were organized, together with other schools to spread the knowledge and expertise as broad as possible.

Despite the potential of the initiatives described in this section, the challenges remain, as the initiatives developed are an unstructured cluster of activities, missing an integral framework to focus on key outcomes.

Rationale of Research

This lack of a guiding framework was acknowledged by the Flemish government. Bringing together the challenges of a shortage of technically skilled workforce, the affordances of XR technologies to address these challenges in K-12 technical and vocational education, and the scattered XR initiatives in Flemish education, identified the need to design a holistic plan. This need fitted within the bigger context of the *Vlaamse Veerkracht* (in English: Flemish Resilience) plan of the Flemish Government (Vlaanderen, 2020) which aims to strengthen the Flemish prosperity and well-being after the Covid19 pandemic, investing 4.3 billion euro over a period of three years (Vlaanderen, 2020). One of the pillars in this plan is to support technical and vocational education as they hold more students from socio-economic vulnerable families (OnderwijsVlaanderen, 2023). As expressed by WEF (World Economic Forum, 2022) XR technologies could contribute in catalyzing education towards bridging the gap with industry needs.

A group of experts was commissioned to draft an *XR Action Plan* (XAP) with policy guidelines on how the Ministry of Education could support in fostering the affordances of XR technologies to strengthen teachers and students in K-12 technical and vocational education. In the remaining of this paper, we describe how we addressed this commission, and how this resulted in a sound, evidence-informed framework.

Methodology

The group of experts consisted of ten researchers with practice-oriented and fundamental research expertise on XR in education. Experts, including the authors, from five higher education institutions in Flanders, worked together with two school leaders and two IT staff members who had implemented XR technologies in their schools. The Department of Education was represented by two policy officials.

The expert group adopted Educational Design Research (EDR) as the methodological framework (McKenney & Reeves, 2018). EDR is a valid framework in this context, since it fits curriculum and large-scale research and development initiatives (Nieveen & Folmer, 2013; van den Akker, 2013). Moreover, it is an iterative approach (see Fig. 1) to address complex educational problems with practical solutions, but also to add to the theoretical understanding of the topic under investigation (McKenney & Reeves, 2018, p. 6).

The first EDR phase focuses on analysis and exploration. A quick scan of the available literature on AR, MR and VR in K-12 technical and vocational education was carried out. Typically, in Educational Design Research both scientific and practice-related resources are investigated (McKenney & Reeves, 2018). First, we searched the internet for blogposts and white papers on how other countries, regions, schools implemented XR in their courses and which lessons learned could be drawn. Second, we searched the *Web of Science* and *Eric* databases for (quasi-) experimental research and for research on acceptance of XR by students and teachers, both narrowed down to K-12 technical and vocational education. For an in-depth discussion of the methodology, refer to Boel et al. (2021a) and (2022). As we were interested in how to implement XR technologies in the actual classrooms, empirical studies with a (quasi-) experimental design were of value to us. Similarly, studies on acceptance and use of XR technologies were expected to provide us insight into factors contributing to or inhibiting the acceptance of school leaders, IT staff members, teachers and students. Studies selected after applying the set inclusion criteria, were analyzed. The results were categorized using the factors from the UTAUT2 framework (Venkatesh et al., 2012), extended with new elements beyond this model. The choice of UTAUT2 seemed valid as at that point in time the use of XR still was a deliberate and autonomous choice by the teacher and not yet being implemented at an organizational level, which was later confirmed (Boel et al., 2021b, 2023a; RTC, 2021).

Next, we drafted a stakeholder mapping. We interviewed five school leaders, five IT staff members, five teachers and five representatives of educational organizations. We investigated their perceptions on XR technology in education, building on the UTAUT2 framework (Venkatesh et al., 2012). All interviews were held online, recorded in MP3-files, and transcribed in full. The transcriptions were then analyzed using *NVivo12*. Four interviews were coded independently by four researchers. Next, the codes identified were compared, discussed and finalized into a codebook, which was used to coding the remaining interviews. More details can be found in Boel et al. (2021b). To complement these results with the learner perspective, we ran a survey with students to investigate their perceptions on XR technology likewise (Boel et al., 2023b). This helped us to understand which needs the several stakeholders expressed and within which context XR technologies should be implemented.

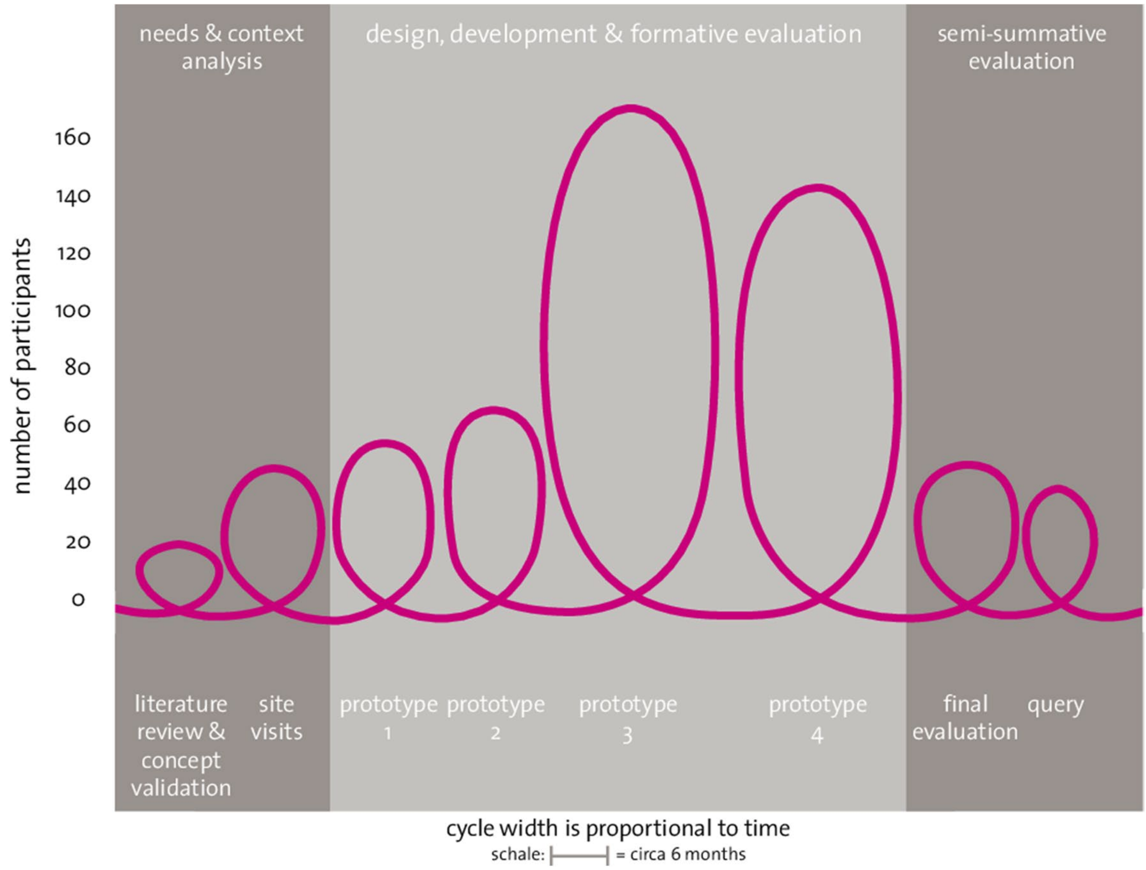

Fig. 1 Visual representation of the iterative development of Educational Design Research (adapted from McKenney & Reeves, 2018)

Finally, all results from the literature search, interviews and surveys were collated and synthetized into a design document containing four products: a problem definition, long-range goals, partial design requirements, and initial design propositions (McKenny & Reeves, 2018, p. 114).

These elements were elaborated in the second EDR phase: the iterative design of the learning solution to address the needs expressed, within the contextual boundaries, considering insights from the literature review. Four researchers from the expert group drafted a first version of the proposal. This first draft was then evaluated formatively by all other experts based on the criteria as developed by McKenney and Reeves (2018, pp. 159–160): the proposal is evidence-informed ("the proposed actions are based on prior research"), appropriate/on task ("it addresses the needs and challenges expressed and fits the request as defined by the Ministry of Education"), clear ("it is written in a sound style to avoid misinterpretation"), feasible ("the proposed actions are feasible within the context of K-12 technical and vocational education"), complete ("it addresses all needs and challenges, and the affordances of all XR technologies") and actionable ("it is goal oriented and activities are specified in detail to attain that goal"). Feedback from all experts was collected in view of a second version. This version too was presented to the expert group to develop a third and finally a fourth version of the document. The final version was presented to the Minister of Education and evaluated positively. Following the approval, a 6.5 million euro subsidy was granted (Vlaams Parlement, 2021) to implement the plan during the period of 2022–2024.

Results and Discussion

The design document resulting from the first EDR phase of analysis and exploration contains four products. First, we defined the problem: although both teachers (Boel et al., 2023a) and students (Boel et al., 2023b) are acceptable to XR for education, teachers lack the facilitating conditions (Venkatesh et al., 2012) to do so effectively (Boel et al., 2021b). Second, the long-range goals are to enhance students' learning performance and motivation, by providing them XR learning experiences. Thirdly, the typical setting of technical and vocational education (e.g. focus on practical courses, close link to industry) has to be taken into account as design requirements. Finally, design propositions were formulated (Boel et al., 2021b). These have been elaborated into five pillars, which will now be discussed in further detail. As we aim to maintain the scope of this paper on the national program itself, the respective results of each research action will not be covered in detail, as they have been described in other research papers (Boel et al., 2021a, b, 2023a, b).

Building on the results of the first EDR phase, we adopted the Four in Balance-model (FIB), as developed by Kennisnet (Schouwenberg, 2022) to design our own framework. The FIB model served well as a basis, as several barriers expressed in the exploratory phase could be mapped to the four pillars of this FIB model: vision, expertise, content and applications, and IT infrastructure. In addition, by improving the didactic proficiency of teachers (teams) when implementing IT for instructional purposes, this model aims to increase students' learning performance (Kenniscentrum Digisprong, 2022), which matches the goal for our proposed framework.

In combining the results of the literature review, the needs and context analysis, with the structure of the FIB model, we defined five pillars in our proposed framework: hardware, software, professional development of teachers, practice-oriented research, and coordination. Figure 2 presents an overview of the five pillars and their respective actions, together with how the pillars are affecting each other.

Hardware

Several studies have indicated that the cost of XR hardware is of concern to school leaders, IT staff and teachers (Boel et al., 2021b; Coban et al., 2022; Kavanagh et al., 2017; Fransson et al., 2020; Pellas et al., 2021; Southgate et al., 2019; Tegoan et al., 2021). Although XR devices have become more affordable and as such in reach for education (Hamilton et al., 2021), they remain expensive and must compete with other learning technologies such as a laptop (Boel et al., 2021b). In addition, most schools have no to little experience with XR (Boel et al., 2023a; RTC, 2021). As such, it is difficult for schools to decide on whether to spend money on XR hardware: they have not yet seen evidence of benefits to education in their own experience (Boel et al., 2021b). Via a free rental system, schools can experiment with different types of XR and investigate if and how XR could fit their specific needs and how XR could be implemented into their existing curricula.

Adding to the basic cost of XR hardware, there is a lack of interoperability (European Commission et al., 2023): XR software is at this point still linked to specific XR hardware. For example: an *Oculus* VR application cannot be accessed by a *PicoXR* headset; an *iOS* AR application is not readily transferrable to *Android* tablets. When schools want to use a diversity of XR applications, they are forced to invest in different types of XR hardware, increasing the cost even more.

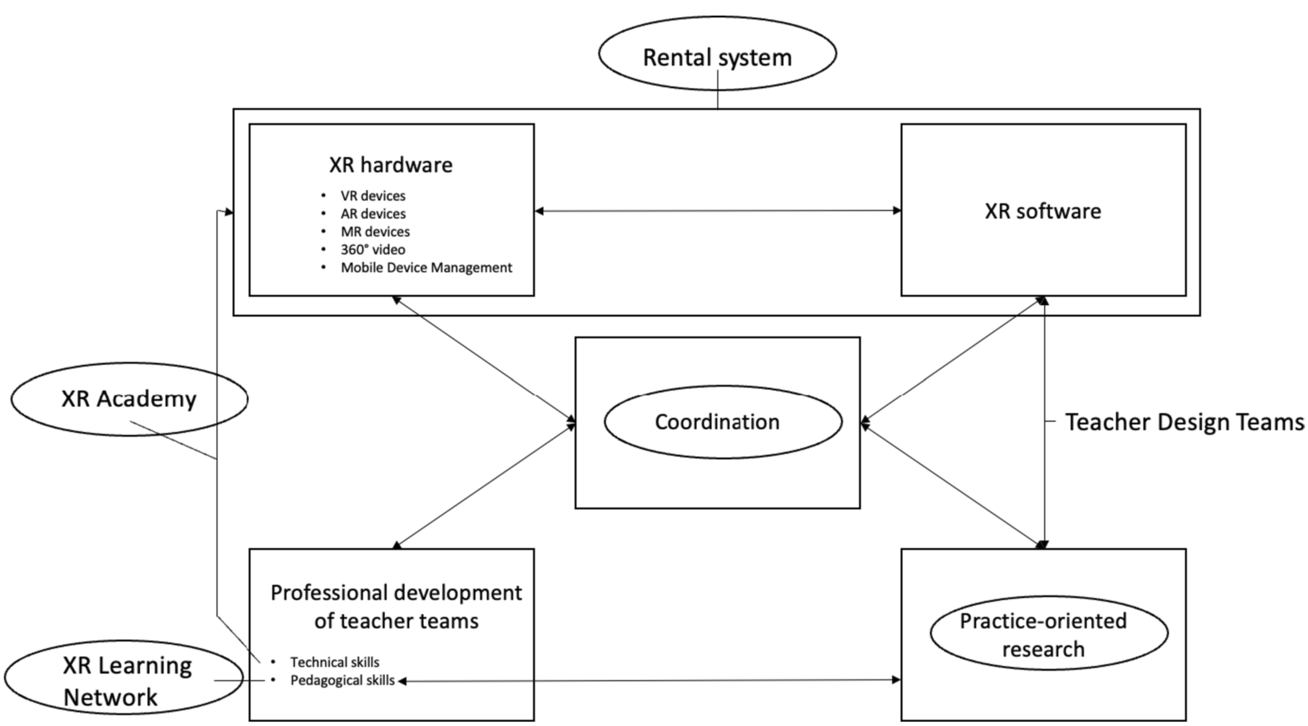

Fig. 2 Visual representation of the five pillars (squares) and their interdependency as part of the proposed framework for a nation-wide implementation of XR in secondary technical and vocational education. Ellipses refer to different organizations taking up the activities

Following this lack of interoperability and to address as many needs as possible, the choice of hardware to invest in and to rent to schools, is based on the availability of selected XR software supported by the devices.

Another concern is the technical complexity related to XR hardware, such as user accounts, software licenses, maintenance and storing of XR hardware, which has often been expressed by IT staff members in schools (Boel et al., 2021b; Pellas et al., 2021; Southgate et al., 2019). As IT staff members are charged with IT hardware and management, this will add to their workload which is already high (Vicli, 2017) hindering the adoption of XR technology (Boel et al., 2021b).

The five Regional Technical Centres occupy a critical position as pivotal stakeholders in the effort to bridge the gap between technical and vocational schools and the industry. Given their existing support for these schools through numerous initiatives, the provision of XR hardware rentals to schools could be seamlessly incorporated into their current offerings. Moreover, the RTCs can tackle the concerns of IT staff on set-up, maintenance and storage. Finally, as the five RTCs install a renting system to schools, there is an important economic benefit of scaling to a national level, as opposed to directly supplying XR hardware to individual schools.

As the RTCs support more than 600 schools and as such more than 3,000 XR devices, a mobile device management system (MDM) is advised. This solution provides for the management of several mobile XR devices at once, with a reduction of time spent on set-up and maintenance of the hardware (Kelly et al., 2023).

> Policy advice for hardware: it is recommended to install a free rental system for schools, in which all technical set-up and maintenance is included, providing schools and teachers with a diversity of XR hardware which is ready to use in the classroom. This rental system should be administered by network organizations who can integrate this in their current programs to support technical and vocational schools. An MDM is recommended.

Software

Although XR hardware poses challenges for implementation in K-12 schools, the lack of qualitative, curriculum-aligned XR software is even of greater concern (Akçayır & Akçayır, 2017; Boel et al., 2021b; , 2019 Kavanagh et al., 2017; Luo et al., 2021; Maas & Hughes, 2020; Pellas et al., 2021; Southgate et al., 2019; Wu et al., 2020). However, several companies worldwide have invested in XR training programs for their staff. These XR applications could benefit the educational field too. A list of XR applications which have been evaluated on their quality, using sound criteria can provide the teachers and the RTC network organizations with a valuable instrument to decide if and with which application they use XR in their courses (Fegely & Cherner, 2021; Johnson-Glenberg et al., 2020; Lee & Hu-Au, 2021). This also addresses concerns of teachers and IT staff members on the time spent looking for qualitative applications and testing them before presenting them to their students (Boel et al., 2021b). As the RTC organizations are on the brink between education and industry, they are the best partner to reach out to companies and elaborate agreements with them to open their XR application for educational purposes.

Implementing existing XR learning experiences will however not address another concern teachers have indicated: the English language of existing XR applications can pose a challenge to their students (Boel et al. , 2021b). Therefore, the existing Dutch XR applications are funded to make them sustainable. Next, new curriculum aligned XR learning content in Dutch is being developed. Rising from actual needs in education, dedicated XR learning experiences are realized within the context of the existing InnoVET program.

> Policy advice for software: it is recommended to draft a list of qualitative XR learning experiences, based on evidence-informed criteria offering schools a practical instrument to decide if and how they want to implement XR in their courses. This list consists of applications both in education and enterprise training. Agreements with enterprises to open their XR trainings to education should be settled. In complement, existing XR learning experiences should be supported towards sustainable learning solutions. Finally, addressing actual needs and gaps for XR applications, new XR learning experiences could be developed, in the mother tongue and in alignment with the national curricula.

Professional Development of Teachers (Teams)

The need for professional development of teachers is a common theme in studies on XR acceptance by teachers as they lack the necessary skills, both technically and pedagogically to implement XR into their courses (Alfalah, 2018; Boel et al., 2021b, 2023a; Khukalenko et al., 2022; Mystakidis & Christopoulos, 2022). As the actual use of XR in K-12 education in Flanders is still low (Boel et al., 2023a; RTC, 2021), a diversity of initiatives is established, addressing all levels of XR expertise in schools.

To be successful and effective, several key elements for the design of professional development initiatives (PDI) have been identified. Core features are content focus, pedagogical knowledge, evidence-based design and ownership; structural features are duration, collaborative participation, school or site-based, active learning and trainer quality (for an in-depth elaboration, refer to Merchie et al., 2016). These features have been confirmed in other research (e.g. Education Endowment Foundation, 2021; Schildkamp et al., 2020). All initiatives developed fit these key elements as best as possible.

To ensure teachers use the XR devices properly (e.g. they know how to set play area boundaries, how to start an application, how to solve basic technical issues) teachers are obliged to follow an XR Academy, a technical training prior to making use of the XR rental system by the RTCs. In this way, teachers will feel more confident to use XR in their courses, increasing their acceptance and use of XR technology (Boel et al., 2021b; Khukalenko et al., 2022; Mystakidis & Christopoulos, 2022).

In complement to this technical training, several didactics-oriented PDIs are organized. The goal is to provide teachers, IT staff members, school leaders and other educational stakeholders (e.g. pedagogical advisory organizations) with evidence-informed information on how to implement XR technologies in education. Similar to the preceding XR Learning Network (see 2.2), two webinars are organized. These webinars focus on basic information on XR in education. In a first webinar, the participants are presented with the initiatives which are being developed in the context of the XAP, the several types within extended reality, the array of XR devices and their ecosystems, the affordances of the different XR technologies, a decision tree on which XR technology is fit for which learning goal, and some examples of existing educational XR applications. The second webinar focuses on pedagogy, based on good practices from research (e.g. Southgate et al., 2019; Fransson et al., 2020 ; Makransky et al., 2019), combined with expertise from domestic schools who have already worked with XR in their courses. Elements discussed are the need for an affordance-oriented approach (Makranksy et al., 2019), an implementation of XR in existing courses instead of replacing them (Mayer et al., 2022), embedding them in schools' pedagogical and IT policies (Boel et al., 2021b), addressing the innovative teachers as a pebble-in-the-pond strategy (Boel et al., 2023a), creating safe learning conditions (Southgate et al., 2019) and didactic guidelines on how to design 360° video lessons (Ewens et al., 2022). These webinars serve a double goal: to present the participants with essential information on XR in education and to inspire them to apply for a second initiative: the 1-on-1 trajectory.

As we know from research on professional development initiatives of teachers, effective PDIs are evidence-informed, long lasting, contextualized, team oriented and focused on implementation (Education Endowment Foundation, 2021). As such 25 piloting schools in K-12 technical and vocational education can apply for a 1-to-1 professional development program. During the webinars, school teams are presented with basic information, but also with several examples of fostering the XR affordances, and with some pedagogical guidelines and approaches. Schools are asked which current challenge they want to address. These challenges can be diverse. Examples are: students have to learn welding in a safe, but also cost-effective way; students have to train their communication skills in various tourist situations but lack authentic learning experiences; students have to train their nursing skills with toddlers, but have only little opportunities to train them during short-period internships. Based on the decision tree as explained during the webinars, the teams have to explain which XR technology they seem fit to address their challenge, and how they want to design their trajectory. An essential selection criterion is the collaborative approach (Merchie et al., 2016). The 25 schools selected, are supported during a full school year, by a member of the XR Learning Network, who is an expert on XR in education. The school team is supported by this expert and together they develop an XR learning solution to address the challenge. This development is tailored to the key elements of an effective PDI (Education Endownment Foundation, 2021; 2020; Merchie et al., 2016); Schildkamp et al., 2020). Building on that, exchanging information and lessons learned, fosters reflective thinking in teachers' pedagogical approaches, i.e. T-Pack (Mishra & Koehler, 2006), and as such, several moments of exchange are organized.

These exchange moments focus primarily on the 25 schools of the 1-to-1 trajectory, but are open to all other schools with an interest for XR in education, and are part of the third initiative of the XR Learning Network: showing school teams the educational affordances of XR technologies via inspiration and demo events. During these events, participants are given the opportunity to experience XR learning solutions. Actually being immersed in an AR, VR or MR learning application, provides a better avenue for acceptance and use than merely being told about it (Boels et al., 2023a; Mütterlein & Hess, 2017; Venkatesh et al., 2016), especially when they are aimed towards a teacher's specific professional field (e.g. carpentry, nursing, gardening) instead of more generalist PDIs covering a wide range of topics (Boel et al., 2021b).

As the XAP is developed under non-recurring funding, it is essential to work towards a sustainable roadmap. When the funding period is over, the established initiatives should be continued as developed, but without a mandatory need for new funding. In line with implementing the XR rental system within existing educational organizations (RTCs), which are recurringly funded, involving the team members of these organizations and increasing their knowledge, expertise and skills on XR in education, provides an avenue for a program with a long-lasting potential. Therefore, members of the other pillars of the XAP participate in the different initiatives of the XR Learning Network. In this way, they increase their overall XR expertise, and are in touch with the needs and context of the schools involved in terms of the XR implementation, providing them with information on how to tailor their own offer to the schools.

> Policy advice for professional development of teachers: it is recommended to establish a diversity of initiatives to address the differing levels of XR expertise of schools, and to design these initiatives according to evidence-informed key features to be as effective as possible. To work towards a sustainable program, members of existing educational organizations should be participating in the professional development initiatives, increasing their XR expertise and securing a continuance of the initiatives established.

Practice-Oriented Research

Several studies have shown the benefits of XR for K-12 education (e.g. Boel et al., 2021a; di Natale, 2020; Hamilton et al., 2021). However, several studies have also expressed the need for more research in actual classrooms (Boel et al., 2021a; Fransson et al., 2020; Southgate et al., 2019), as "conducting research in natural settings is very different from inquiry enacted in controlled experimental, laboratory or clinical research. Classrooms are socially active, sometimes unpredictable, places that yield unique and credible insights into the deployment of technology 'in the field'." (Southgate et al., 2019, p. 20). As such, complementing the 1-to-1 trajectory of the professional development initiatives, practice-oriented research is carried out to investigate how student learning can be fostered using XR technologies in an actual classroom. Following a design-based approach as suggested by Makransky et al. (2019), Teacher Design Teams (TDT) are established in the 25 piloting schools. This methodological framework of TDT aims to (re)design educational materials (Binkhorst et al., 2015) and has several overlaps with the features of effective PDIs (Merchie et al., 2016; Schildkamp et al., 2020) such as an iterative approach, school support, collaborative design, school based and focused towards change in practice.

The systematic approach of TDT offers opportunities to investigate both the process and the outcomes of the design projects. As a methodological framework for the TDT, Educational Design Research (McKenney & Reeves, 2018) is adopted, as this model serves two outcomes: a learning solution with a practical impact in actual learning settings and second a contribution to the academic literature on designing learning solutions. An EDR approach is well-suited within the TDT program: schools will be able to use actual XR learning solutions tackling real challenges and researchers involved will be able to define guidelines to design effective XR learning solutions in K-12 technical and vocational schools. This is of interest as several studies have indicated there is a lack of sound instructional design principles for XR learning applications (Boel et al., 2021a; Chavez & Bayona, 2018; Radianti et al., 2020; Wu et al., 2020), sometimes even leading to detrimental effects on student learning outcomes (Makransky et al., 2019). When adopting an EDR approach, researchers involved in the TDT can focus explicitly on developing, testing and validating design guidelines.

As the Teacher Design Teams work in "ecologically valid" settings (McKenney & Reeves, 2018 p. 82), they can provide researchers with rich data on the perceptions of both students and teachers on XR for learning; how they might evolve during the design project; on how XR learning applications fit or are being fitted within existing curricula; and how teachers, IT staff and school leaders adapt their pedagogical and IT views, policies and school organization to benefit from the newly developed XR learning solutions. Insights from this research is of value to other researchers as they are empirically grounded and rooted within a systematic methodology.

> Policy advice for practice-oriented research: it is recommended to investigate how effective XR learning applications are designed, in a Teacher Design Teams approach, adopting Educational Design Research as a methodological framework. In complement or as part of it, research should investigate how the newly developed XR learning solutions are implemented in existing curricula and how teachers, IT staff and school leaders fit XR technologies for learning within their pedagogical reasoning and pedagogical, IT and infrastructural policies.

Coordination

As depicted in Fig. 2, all pillars are affecting each other's effectiveness. Therefore, coordination of the actions and goals of each of those pillars is essential. Hardware and software are to a large extent intertwined, due to a lack of interoperability (European Commission et al., 2023). School teams who want to use the XR rental system must follow an XR Academy first. The XR Learning Network makes use of the hardware provided by the rental system to support the school teams pedagogically. Researchers work together in Teacher Design Teams during the 1-to-1 trajectory of the XR Learning Network and strive for guidelines which can further the initiatives of all pillars' organizations. This calls for a strong coordination to overview all actions and streamline them towards the same goal: supporting school teams in their implementation of XR technologies in education.

In line with the development of the XR rental system, fitting this coordination within an existing organization, thus creating a sustainable avenue, a specific unit of the Department of Education in Flanders, responsible for all matters concerning educational technology, namely *Kennis- en Adviescentrum Digisprong* (KACD) takes up this role of coordinator of the XAP. KACD is a Dutch abbreviation which stands for Knowledge and ExpertiseCentrum Digitalisation Leap, dedicated to support schools with funding, policy notes and technical and pedagogical guidelines on how to foster the affordances of educational technologies (Vlaanderen, 2023).

Three members of KACD are complemented with representatives of each of the four other pillars and if needed XR field experts, in a steering group to discuss progress of the XAP and make arrangements to align with each other's goals and the overarching goal.

> Policy advice for coordination: it is recommended to establish a coordinator to ensure all activities of the respective pillars align with the other pillars' activities and goals, in support of the common goal of the XAP. This coordination should fit within the activities and goals of an existing educational policy organization to be as sustainable as possible. The coordinator should be complemented with representatives of the four other pillars and, if needed XR field experts, in a steering group to secure coordination and alignment.

Implications and Limitations

This study has both theoretical and practical implications, typical of EDR (McKenny & Reeves, 2018). The proposed framework might guide other researchers to design, develop and test large-scale implementation programs on XR in education. Likewise, the same guidelines can be used by education policy makers worldwide, serving also a more practical goal.

The value of our proposed framework was acknowledged by the Minister of Education and a total funding of 6.5 million euro was granted to the several organizations involved. The plan is now being implemented in K-12 technical and vocational schools in Flanders. An evaluation of the XAP is expected by 2025.

That makes it one of the limitations of our work: an evaluation has not yet carried out. However, the proposed framework was developed using the systematic methodology of Education Design Research (McKenney & Reeves, 2018), involving all relevant stakeholders, based on a needs and context analysis. The proposed actions are all evidence-informed. A second limitation is the specific context of the Flemish region and K-12 technical and vocational education. Although it can guide education policy makers and researchers in other regions and nations worldwide, it should be adapted to its specific context. The needs and contextual factors such as existing infrastructure, educational policies, and stakeholders might differ and these should be taken into account when developing such large-scale programs (Mütterlein & Hess, 2017; Venkatesh et al., 2016).

Conclusion

This paper describes how we designed and developed a framework for a nation-wide implementation of augmented, virtual and mixed reality in K-12 technical and vocational education. We adopted Educational Design Research (McKenney & Reeves, 2018) as a systematic methodology. Based on a needs and context analysis, in combination with insights from previous research and field expertise, we designed a framework, consisting of five core pillars: hardware, software, professional development of teachers, practice-oriented research, and coordination. This framework was approved and granted 6.5 million euro by the Ministry of Education to develop the several pillars into practice. This paper has both theoretical and practical implications as it might guide both researchers and education policy makers to use this framework for the implementation of XR technologies in education, when adapted to the specific educational and national context.

Acknowledgements The authors would like to thank the following persons for their input and feedback: dr. Frederik Cornillie from itec KULeuven, Steven Hendrickx and Lars Vandeput from KA Keerbergen, Michaël Empsen from PXL University of Applied Sciences, An Serneels and Alexander Vanhulsel from Thomas More University of Applied Sciences, Basiel Bonne from HoWest University of Applied Sciences and Naomi Wauterickx and Debby Peeters from the Flemish Department of Education.

Author Contributions all authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Carl Boel, Kim Dekeyser and Dieter Struyf. The first draft of the manuscript was written by Carl Boel, Kim Dekeyser, Marijke Lemal and Dieter Struyf, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding No funding was received for conducting this study.

Declarations

The research was conducted according to the ethical rules presented in the General Ethical Protocol of the Faculty of Psychology and Educational Sciences of Ghent University, in accordance with the Declaration of Helsinki. All participants signed an active informed consent prior to the start of the study.

Ehics Approval This theoretical study builds on previous studies. No new data were collected, as such ethics approval was not needed. The research however was conducted according to the ethical rules presented in the General Ethical Protocol of the Faculty of Psychology and Educational Sciences of Ghent University, in accordance with the Declaration of Helsinki.

Consent to Participate As we did not collect new data, informed consent was not needed. The informed consent from the prior studies on which we built our theoretical framework, is added in the next section. In that informed consent, consent to participate is included.

Consent to Publish As we did not collect new data, informed consent was not needed. The informed consent from the prior studies on which we built our theoretical framework, is added in the next section. In that informed consent, consent to publish is included.

Informed Consent Informed Consent from prior studies on which the framework was built:

I declare that in participating in the study from Thomas More University of Applied Sciences and Ghent University, under the supervision of prof. Dr. Tammy Schellens of Ghent University (Department of Psychology and Educational Sciences):
1. I have received explanation on the nature of the questions and the tasks that will be presented to me during this research, and that I was offered the opportunity to obtain additional information; I understand what is expected of me during this research;
2. I participate in scientific research completely of my own free will;
3. I give permission to the researcher to store, process and report on my data after they have been fully pseudonymized. No personal data such as name or e-mail will be collected. All data collected will be pseudonymized, using a randomly generated 6-digit code. The file linking the individual answer to the code is only available to the responsible researcher and secured with a password. This file will be destroyed after 5 years;
4. I am aware that not participating is this study does not affect my evaluation negatively; I know that I will not receive any further reward or compensation for my participation;
5. I am aware of the possibility of withdrawing my participation from the study at any time without giving any reason;
6. I know that I can receive a summary of the research findings after the study has been completed; this summary by no means allows for tracing data or analysis back to individuals, or institutions;
7. I know that Thomas More University is the responsible unit with regard to personal data collected during the research. For questions and for the execution of my rights (access to my data, rectification of the data, …) after my participation I know that I can contact the responsible researcher Carl Boel at: carl.boel@thomasmore.be. I know that the data protection officer can provide me with more information about the protection of my personal information at: privacy@thomasmore.be.

Competing Interests The authors declare they have no financial interests; there are no other conflicts of interest.

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