XR ASSOCIATION

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National Science Foundation
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Dear National Science Foundation,

The XR Association (XRA) is pleased to submit comments in response to the National Science Foundation's (NSF) Request for Information (RFI) on Developing a Roadmap for the Directorate for Technology, Innovation, and Partnerships (TIP).

XRA is a trade association that represents the broad ecosystem of XR industry stakeholders including hardware manufacturers, technology platforms, software developers, component and peripheral companies, internet infrastructure companies, enterprise solution providers, and end-users. Our members run the gamut from the world's biggest technology firms to start-up companies with just a handful of employees. Our mission is to promote responsible development and thoughtful advancement of XR to foster positive societal outcomes. We are leading the way on virtual reality (VR), augmented reality (AR), and mixed reality (MR) – collectively "XR" technology – by convening stakeholders, developing research and best practices, and advocating on behalf of our members and the broader XR industry.

This public comment will address the topics of Prioritization, Suitability, Workforce, Addressing Societal Challenges, and Crosscutting Investments that are included in the RFI. In the following pages we will outline how immersive technology can be used to address key societal, national, and geostrategic challenges; the workforce needs of the XR industry; where investments in XR could serve as a multiplier for other key technology focus areas; and why XR technology is well-suited for NSF research and should be prioritized for funding.

I. Introduction

Immersive technology is poised to change the way we work, play, learn, and engage with one another. Unlike traditional two-dimensional (2-D) mediums, XR technology offers users a sense of physical presence and agency, enabling them to actively participate and manipulate their surroundings. XR has the capacity to transport individuals to new places, simulate scenarios that are difficult to replicate in real life, and provide experiential learning opportunities that were previously inaccessible or limited. With XR, users can visualize complex data, manipulate 3-D models, and gain insights in a spatial context, opening up new possibilities for data visualization and analysis. XR's transformative nature lies in its potential to enhance productivity, enable remote collaboration, and make how we interact with information, objects, and each other more natural and intuitive. The immersive nature of XR facilitates deeper engagement and improves retention, making it a powerful tool for education, training, and skills development across diverse fields. Although XR is still relatively nascent, it is already having a positive impact in sectors including healthcare, education, manufacturing, public safety, urban planning, and more.

II. Addressing Societal Challenges

As will be discussed throughout this paper, XR technology has become integral to many of the United States' most important sectors, and it is preparing our workforce for the future as well as augmenting our defense capabilities. Immersive technology possesses unique qualities and capabilities that make it particularly well-suited to address U.S. competitiveness and the societal, national, and geostrategic challenges identified in the RFI.

National Security: Immersive technology has become essential to U.S. national security and has officially been designated a critical technology.[i] [ii] The United States military was one of the earliest adopters of immersive technology and continues to use XR for training and warfighting. XR is used to help prepare soldiers for combat in different environments from dense urban cities to remote jungles. The Department of Defense has also explored ways to use VR to train medical personnel as military medics often face situations that are difficult or dangerous to replicate in real life. XR is being used by the Air Force to train pilots against drones, advanced tech capabilities, and adversaries in real-time environments in their actual aircraft. Warfighters also rely on immersive technology for real-time sensor information and communication to improve their situational awareness.

There are numerous challenges wherein the NSF could help drive XR development in this area. The NSF could conduct research to improve the form factor of XR technology and make it more rugged for national security applications. Specifically, NSF could support research to make XR sensors and components more resilient for deployment on the battlefield and harsh training environments. Research could be conducted to address cybersecurity challenges associated with immersive technology, including securing XR devices, preventing unauthorized access, and safeguarding sensitive data. This research would contribute to ensuring the integrity and confidentiality of immersive technology systems used in national security contexts. New research could also explore the effectiveness of immersive training environments for military personnel, enhancing their decision-making skills, situational awareness, and mission readiness. Moreover, the NSF could explore the development of security measures to protect against the misuse of immersive technology (e.g. ways to detect and prevent the use of XR for training by terrorists).

Manufacturing & Industrial Productivity: In the manufacturing field, XR technology is making it easier to design and model products virtually, without having to recreate costly prototypes. Virtually modeling components and products improves quality and reduces time-to-market across the industrial landscape. Manufacturers are also using augmented reality on the factory floor to provide guided instructions for fabrication of parts and real-time assistance. Immersive technology can help make manufacturing processes safer and more efficient which in turn strengthens the domestic production capacity.

In this area, the NSF should consider researching advanced virtual simulations and digital twins that accurately replicate manufacturing processes, machinery, and environments. This research could focus on enhancing the realism, accuracy, and interactivity of these simulations to provide an immersive training and planning tool for improving productivity and operational efficiency. Additionally, research could be conducted to develop intuitive user interfaces and interaction methods for immersive technology in manufacturing settings. This research would aim to create seamless and efficient ways for workers to interact with digital information, virtual objects, and control systems within an immersive environment. Such research would help optimize the use of immersive technology in manufacturing settings, enhance industrial productivity, streamline operations, enable remote collaboration, improve worker training, and drive overall efficiency gains across all sectors in the U.S.

Workforce Development and Skills Gaps: Across all industries, XR is helping to prepare people for the future of work. The interactive nature of XR training keeps learners engaged and motivated to complete the training, leading to better overall learning outcomes. Immersive technologies allow workers anywhere to learn in-demand skills at their own pace and receive instant feedback, enabling them to identify areas for improvement and track their progress effectively. Immersive technologies can help break down barriers and create educational and workforce training opportunities in remote, geographically dispersed, and underserved communities. XR technology has also been shown to improve knowledge and skills retention and workplace safety. Moreover, immersive technologies are more cost-effective, reducing the need for expensive learning and training facilities. XR training can be replicated and deployed to multiple participants without additional expenses. Integrating XR into workforce development exposes people to cutting-edge technology, equipping them with skills that align with modern industry trends and innovations.

Here, XRA encourages the NSF to conduct research that supports inclusion and equity in workforce development. This research could explore the ways in which immersive technology can be used to support social inclusion and equity in workforce development, such as by providing training opportunities to workers from marginalized communities, by making training more accessible to people with disabilities, or by building bridges to more geographically dispersed and diverse-owned businesses. Additionally, research should be conducted to explore the integration of immersive technology with competency-based assessments and certifications. This would involve developing immersive assessment methods that accurately evaluate an individual's skills and competencies in a simulated work environment, enabling more reliable and efficient skills recognition and credentialing. Research in these areas would contribute to the effective utilization of immersive technology for workforce development, closing skills gaps, and ensuring that individuals are equipped with the skills needed for the evolving job market.

Climate Change and Environmental Sustainability: XR technology can also be used to keep people safe and mitigate the effects of natural disasters and climate change. For example, by creating a “digital twin” of flood scenarios, officials can examine an online model and better assess potential impacts. Immersive technology is also being used to educate and raise awareness about the negative effects of climate change. XR can also improve remote collaboration and reduce unnecessary travel.

XRA encourages the NSF to explore the effectiveness of immersive technology in engaging and educating individuals about the impact of their actions on the environment, promoting behavioral change and sustainable decision-making. The NSF could also research the integration of immersive technology in sustainable design and manufacturing processes. This includes using VR and AR to optimize product design for sustainability, simulate material choices and their environmental impact, and streamline manufacturing workflows to reduce waste and energy consumption. Moreover, the NSF should consider investigating the use of immersive technology, to create virtual simulations for environmental planning, conservation, and impact assessment. This research would explore how immersive experiences can help policymakers, planners, and conservationists visualize and evaluate the potential environmental consequences of projects, allowing for more informed decision-making and sustainable resource management. Similarly, NSF research could support the creation of a repository of reusable virtual artifacts that serve the public interest. For example, a virtual representation of the City of San Francisco, that could be extended by the general developer community (similar to the open-source software model) could serve as a uniform resource underpinning the development of a vast universe of public service applications supporting environmental sustainability such as traffic pattern modeling, disaster recovery, civil engineering, urban planning, and more. By conducting research in these areas, NSF can help harness the power of immersive technology to drive awareness, promote sustainable practices, facilitate environmental planning, and enhance decision-making towards addressing climate change.

Access to Education, Opportunity and Other Services: Immersive technologies can be used to expand access to essential services like education and healthcare as well as job opportunities. XR can expand patients' access to specialized care. For instance, the Department of Veterans Affairs uses VR technology to help soldiers teach to stress management and relaxation techniques.[iii] XR technology can also improve the accessibility and convenience of key human services. Content such as learning modules or patient therapies can be downloaded directly to XR devices allowing people to access them even in areas where access to high-speed internet is limited. The ability to use XR remotely can also make it easier for individuals who are not able to access specialized educational opportunities or healthcare services nearby. XR technology can also be personalized and adapted in real time.

XRA encourages NSF to conduct research to explore the development of immersive virtual learning environments that provide equitable access to quality education, especially for underserved communities. This research would involve identifying barriers to access and designing immersive educational experiences to bridge educational gaps, enhance student engagement, and personalize learning. Research in this area could also help address the shortage of teachers in the United States. NSF could investigate the role of immersive technology in teacher training and professional development. This research would explore how XR can be used to enhance teacher preparation programs, facilitate remote collaboration among educators, and foster the development of immersive content creation skills. It would aim to empower educators with the knowledge and skills necessary to effectively integrate immersive technology into their curriculum.

The use of XR to expand access to healthcare is another area the NSF should prioritize. The NSF should consider studying the integration of immersive technology into telemedicine platforms and the effectiveness of XR in facilitating remote consultations, patient monitoring, and healthcare delivery, especially for individuals in remote or underserved areas. XR has also been shown to be promising in providing stress reduction and general wellness techniques. Research in this area could involve developing immersive experiences that target specific fears, and evaluating their impact on stress reduction, coping skills, and overall well-being. Additionally, investigating the long-term effects and potential for sustained improvements through immersive interventions would be valuable.

Accessibility: XR hardware is rapidly evolving, and while some facets are unique to individual manufacturers, the XR industry is working to maximize accessibility in conjunction with software development partners. However, this is also an area where NSF research could make a tangible impact in ensuring that there are accessibility tools that allow for those with disabilities to use immersive technologies across all of the critical applications discussed in this paper. Therefore, we encourage the NSF to fund research and implementation of findings for how to integrate accessibility tools and standards into all XR uses. This research could explore developing customizable user interfaces and control mechanisms that cater to individuals with diverse physical abilities and would enhance inclusivity. The NSF could also research gesture recognition and voice-command systems to replace traditional input methods and could empower those with limited mobility to interact more seamlessly within immersive environments. Additionally, the NSF could investigate ways to optimize XR experiences for users with sensory impairments, such as incorporating haptic feedback and audio cues which would enrich their engagement.

Across all these societal, national, and geostrategic challenges identified by the CHIPS and Science Act and included in this RFI, immersive technology is helping the U.S. government and private sector mitigate risks, identify answers, and optimize implementation of solutions. XR has immense potential to help the United States meet the challenges of today and the future. However, more research is needed to fully realize the benefits of the technology and ease its adoption. XRA encourages NSF to prioritize these research topics to ensure that the U.S. remains at the forefront of this technology.

III. Workforce

The XR industry is poised for significant growth and innovation. A report by McKinsey & Company estimates that the metaverse could have a market impact of around $5 trillion by 2030.[iv] The expected growth of immersive technologies will lead to a significant surge in workforce needs. As XR technologies continue to advance and find applications across various sectors, there will be a demand for skilled professionals in areas such as XR content development, software engineering, user experience design, and XR system integration, creating new job opportunities and requiring a specialized workforce to drive the industry forward.

Research from Jobs for the Future identified four categories of emerging new jobs that will be needed as adoption of XR continues to grow.[v] These new roles include:

1. *XR experience builders and developers* (e.g. AR/VR software engineers, Unity and Unreal Engine developers, graphics software engineers, security architects, and UX architects and researchers) will be essential to develop the hardware for immersive

technology, such as headsets, glasses, and haptic devices, as well as the software that will leverage sensor data and create immersive environments.

2. *XR innovation facilitators and solution architects* (e.g. 3-D artists, economists, human-factor engineers, technical artists, and visual effects artists) will play a crucial role in generating new applications of immersive technology and serve as subject matter experts to ensure that virtual environments and content align appropriately with physical environments. The XR industry will need skilled workers familiar with 3-D engines and emerging generative AI technologies beyond the confines of the games and entertainment sectors. Overcoming the current bottleneck in content development will also require empowering individuals without formal design training to actively participate in everyday 3-D content creation, enabling professionals from diverse disciplines to efficiently produce tailored content that aligns with their specific business needs.

3. *XR technology enablers* (e.g. program managers, design leads, and privacy managers) will help ensure that immersive technology is deployed properly throughout organizations. These roles will require a mix of soft skills such as communication and customer service and specialized expertise in how immersive technology works and can address business needs.

4. *XR technical support specialists* (e.g. field service technicians, simulation technicians, technical trainers, and XR technical support) will be critical to the continued use of immersive technology and will provide support to ensure users understand and can use XR tools and to ensure that the immersive program meets the needs of the user.

Across all these career pathways, it is a priority for the XR Association and the XR industry to build a diverse and equitable workforce. XRA encourages NSF to structure TIP workforce programs that keep in mind individuals with barriers to employment. To that end, XRA has endorsed H.R. 3211, the *Immersive Technology for the American Workforce Act*, which would establish a grant program for community colleges and career and technical education centers to develop programs for workforce development using immersive technology, prioritizing rural and underserved areas. This type of program would help democratize access to cutting-edge technology. Moreover, many of the skills needed to build XR technology should not require a four-year college degree. NSF should consider programs that bring individuals into the XR workforce through innovative methods such as credentialling, short-term training programs, and work-based learning.

And while it is essential that we must have a skilled workforce to create immersive technology and virtual environments, XR itself is also a tool that can be used to meet the growing demand for workforce training in critical industries. Already, workers are increasingly expected to upgrade their skills quickly and efficiently throughout their careers. The World Economic Forum’s Future of Jobs report estimates that by 2025 over half of all employees will require “significant” reskilling, increasing the demand for workforce development and training programs.[vi] XR technology can help bridge this gap.

Use of XR technology allows off-site training, aids in learning retention, improves collaboration, and is cost-effective. Studies have shown that individuals taught in XR complete training up to four times faster and are 275% more confident to act on what they learned in training.[vii] In practice, XR can provide immersive simulations for training employees on complex machinery operation, safety protocols, and assembly processes, improving efficiency and reducing risks in the manufacturing and industrial sector. Immersive technologies, such as digital twins, can also aid in visualizing and prototyping designs, enabling collaboration, and reducing errors in the building and production process. In healthcare, XR can simulate medical procedures, enabling healthcare professionals to practice and refine their skills in a safe and controlled environment. Moreover, in the transportation sector, XR can offer realistic virtual training scenarios for pilots, drivers, and operators, enhancing their situational awareness and decision-making abilities. By leveraging XR technology, these key sectors can effectively address the demand for workforce training, leading to enhanced productivity, safety, and overall performance.

IV. Prioritization and Suitability

Throughout this paper, we have highlighted the many ways XR technology is critical to advancing U.S. competitiveness and can help meet the United States' strategic objectives. And as is evident from the applications and research topics described in the previous sections, immersive technology has the capacity to revolutionize critical industries such as manufacturing, defense, healthcare, and education by enhancing productivity, improving training and skills development, expanding access to critical human services, and enabling new forms of innovation. XR technology's transformative potential and broad societal impact makes it particularly well-suited for use-inspired and translational research. By investing in XR research, the NSF can contribute to economic growth, strengthen U.S. competitiveness, and boost job creation, while also addressing societal challenges.

Moreover, many other countries – both U.S. allies and strategic competitors – have already recognized the importance of immersive technology to economic success and competitiveness and have taken actions to nurture and support its growth and adoption. For instance, China's 'Action Plan for the Integration and Development of Virtual Reality and Industrial Applications (2022-2026) outlines what policymakers were supposed to do to nurture XR. Specifically, the document lays out that China would establish 100 'backbone enterprises,' 10 regional concentration areas, and 10 public service platforms (to support technical research, content development, and showcase and incubate pioneering applications), and achieve an overall market value of over 350 billion yuan (over $50 billion), by the end of 2026.[viii] Similarly, South Korea's Ministry of Science and ICT published the Immersive Economy Development Strategy. Korean officials aimed to use this strategy to become one of the top five countries in the world for XR, with a domestic economic impact of $23 billion by 2025.[ix] And just last month, the European Union announced over $10 billion USD to support European leadership in critical technologies, including VR, as part of the Strategic Technologies for Europe Platform (STEP).[x] In order for the United States to remain competitive in XR, it is imperative that U.S. government agencies, like the National Science Foundation, prioritize immersive technologies with the same urgency as our allies and adversaries.

To help the United States fully realize the potential benefits of immersive technology, we strongly encourage the National Science Foundation to prioritize immersive technology in its Roadmap for the Technology, Innovation, and Partnerships Directorate.

V. Crosscutting Investments

While the U.S. must support the growth of individual key technologies, it is also important to recognize the bigger picture of the technology ecosystem. XR is interrelated and dependent on many of the other key technology focus areas cited in the CHIPS and Science Act such as artificial intelligence, semiconductors, robotics, medical technology, advanced communications technology, and energy technology. Advancements in one of these areas will impact and generate breakthroughs in the others. As such, there are also needs and research gaps that are common to all these areas that could inhibit the growth and adoption of these key technologies. To help mitigate some of these common challenges, XRA encourages the National Science Foundation to explore research in the following areas.

High Performance Computing: High-performance computing (HPC) systems are listed as key technology focus areas in the RFI. For XR, HPCs provide the computational power necessary for complex simulations, rendering realistic graphics, and enabling real-time interactions within immersive environments. XR technology needs the ability to process the richer data needed in real-time 3D generation. By investing in HPC infrastructure and advancements, the NSF can help enhance the quality and realism of XR experiences.

Semiconductors: Chips are similarly listed as a key technology focus area. Research in semiconductor technologies can lead to advancements in processing capabilities, energy efficiency, and miniaturization, enabling more compact and powerful XR devices with longer battery life.

Display & Optics: While display technology is not explicitly cited as a key technology area, advancements in this domain would support not only immersive technology, but also artificial intelligence, robotics, medical technology, and more. For XR, display technology innovations, including advancements in resolution, refresh rates, and color accuracy, directly impact the visual quality and realism of immersive experiences. Higher-resolution displays with faster refresh rates contribute to reducing motion sickness and enhancing user comfort. Graphics processing units currently cannot run rendering algorithms at the frame rates needed for seamless blending of the virtual and real environments in AR. Display technology is also not advanced enough to generate the brightness necessary for daytime visibility in a form factor that is sleek and comfortable. And finally, waveguides play a crucial role in AR devices by directing and guiding light to create virtual images overlaid on the user's view of the physical world. However, there is a need for further research to enhance waveguide performance, such as improving light transmission efficiency, reducing optical aberrations, and increasing the field of view. Addressing these research gaps is vital for XR as it directly impacts the visual quality, clarity, and immersion of augmented reality content, enabling users to seamlessly interact with virtual elements in their real environment.

Energy: XR devices are energy-intensive due to the computational requirements for rendering high-resolution graphics, processing real-time data inputs, and powering the display systems. Greater research is needed to develop batteries that extend usage time, improve energy density, and reduce environmental impact. This is a research area that would also drive benefits in AI, robotics, advanced communications, industrial efficiency technologies, and much more.

Digital Twins: Digital twins rely on many emerging technologies such as the Internet of Things (IoT) and sensors for real-time data collection, AI for advanced analytics and pattern recognition, and XR to enable visualization and interaction. Digital twins have a broad array of applications and can enable more optimized planning in everything from engineering and design to manufacturing and transportation systems. As we move towards smart cities, digital twins can help us optimize urban planning and construction as well as create a more sustainable environment. Digital twins have significant crossover with other key technology areas in this RFI, but especially natural disaster mitigation, biotechnology, and industrial efficiency technologies. Moreover, other countries have begun to leverage digital twins for government operations and services. For example, in the United Kingdom's 2021 Innovation Strategy, the government committed to consulting the public on the "potential value of and options for a national capability" in 'cyber-physical infrastructure'.[xi] Just last month, the UK announced that it intends to use a digital twin to address one of the "world's most difficult scientific and engineering challenges" – to develop the country's first fusion energy plant.[xii]

The NSF should explore research supporting the scalability and interoperability of digital twins, particularly for use by the federal government. This research could focus on developing standards, protocols, and frameworks that facilitate interoperability and seamless integration of digital twins, enabling cross-domain data exchange, collaboration, and knowledge sharing. Additionally, exploring approaches to handle the vast amounts of data generated by interconnected digital twins would be critical. This research would contribute to the development of practical solutions and foster innovation in digital twin applications, ultimately improving efficiency, performance, and decision-making in complex systems and processes.

Human Factors: Human factors research in AR and VR technology intersects with other tech areas such as robotics, AI, semiconductors, and batteries in several ways. It influences the design and integration of user interfaces and interactions in robotic systems, enabling intuitive and natural human-robot collaboration. Human factors research also informs the development of AI algorithms that enhance user experiences and optimize virtual environments for AR and VR applications. Furthermore, advancements in semiconductors and batteries influenced by human factors research contribute to the creation of more immersive and energy-efficient AR and VR devices, enhancing user comfort and overall performance. Human factors research is crucial in AR and VR technology to ensure optimal user experiences and address potential challenges.

The NSF should explore research that facilitates greater understanding of how users perceive, interact with, and navigate within virtual environments. More research in this area is essential for designing intuitive interfaces, minimizing motion sickness, and optimizing user comfort. This research should also consider assessing the impact of AR and VR on human cognition, physiology, and safety, enabling the development of guidelines and best practices that enhance usability, accessibility, and user comfort in immersive technologies.

These research topics represent opportunities for unlocking the synergistic potential of XR and other emerging technologies. By investing in interdisciplinary collaborations and research initiatives, the NSF can foster innovation, drive technological advancements, and unlock new applications and capabilities in these intersecting fields.

VI. Conclusion

Recognizing the transformative and beneficial potential of XR, we encourage the NSF to prioritize research, development, and workforce programs that leverage its unique capabilities to drive innovation, competitiveness, and address societal challenges. We welcome further discussion on this topic and are glad to answer any questions you may have. Thank you for your thoughtful consideration.

Sincerely,

Elizabeth Hyman, CEO
XR Association

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