Augmented Reality (AR) and Virtual Reality (VR) in the Context of Education: Transforming Learning in the Digital Age

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

The intersection of education and technology has undergone a profound transformation, largely driven by the revolutionary impact of Augmented Reality (AR) and Virtual Reality (VR) technologies. These digital innovations, poised to reshape education, have the potential to redefine the educational experience by seamlessly integrating information into the real world, providing students with immersive and interactive learning experiences. While they share a close connection, they employ distinct methods for engaging with reality and virtual experiences. AR superimposes virtual elements onto the physical world, allowing interaction with a blend of real and virtual content, while VR immerses users fully in a virtual environment, making them a part of the digital world. The core of my research delves into the complex impact of AR and VR on learning processes, with a particular focus on the Architecture, Engineering, and Construction (AEC) industry. One of the unique contributions of the research lies in its incorporation of a primary data collection phase, involving interviews with key stakeholders in the AEC industry. The approach ensures a deeper understanding of the real-world implications of AR and VR technologies, utilizing the experiences and perspectives of those directly involved in implementing these technologies in educational settings.

My research aligns with the broader goal of classifying and quantifying the effectiveness of AR and VR applications in the AEC education sector, and viewed through an STS lens, it aims to understand the historical development, affordances, and limitations of AR and VR, as well as their broader societal implications. Because STS emphasizes the intricate interplay between technology, education, and societal systems, it recognizes that the impact of AR and VR technologies extends beyond the classroom, influencing cultural perceptions of learning, economic structures, and educational policies. The adoption of these technologies is shaped not only by their technical capabilities but also by a myriad of social factors, as outlined by the Social Construction of Technology (SCOT) framework.

Technological and Societal Dynamics

The SCOT framework is a sociological perspective that examines the development and impact of technology by emphasizing the social processes, actors, and contexts involved in shaping technological artifacts. Technologies are socially constructed through a dynamic interplay of various factors; SCOT proposes that technological artifacts are not inherently defined but are subject to multiple interpretations by different social groups. This theory suggests that humans are the ones who create and control technology; therefore, humans determine its application within specific contexts. Understanding a technology's adoption requires insight into how it is integrated within its social context. This theory suggests that technology's development and use involve a process of selection among technology develops and various other social groups, leading to a model that accounts for both successful and unsuccessful technologies. Interpretative flexibility, relevant social groups, and closure and stabilization are its main components.

The interpretation and importance of a technology evolve as diverse stakeholders negotiate and reach a general agreement. This highlights the inherent interpretative flexibility involved in both developing and adopting technologies, allowing for multiple design possibilities for a technological artifact. The framework identifies "relevant social groups" as key actors who participate in shaping and defining a technology. These groups, which may include engineers, policymakers, and other advocacy groups, contribute diverse perspectives and interests as they might hold distinct interpretations of a functional technology, influencing the trajectory of that technological development. The development process persists until a consensus is reached among all groups, signifying that their shared creation is effective. Different social groups may encounter distinct issues with an artifact, leading to group-specific interpretations and developments. The conclusion of the design phase is not solely determined by the objective functionality of the artifact but rather by the collective acknowledgment from relevant social groups that it fulfills its intended purpose.

Closure and stabilization is the third element of the framework. In a multigroup design process, conflicts may arise when divergent interpretations result in conflicting perceptions of an artifact. The design process persists until these conflicts are resolved, and the artifact no longer presents issues for any relevant social group. At this point, the multigroup process reaches closure, and further design modifications cease, leading to the stabilization of the artifact in its final form. A definitive decision, or at least a cessation of additional decision-making, takes place. Rhetorical closure involves declaring that no further problems exist, and additional design is unnecessary. Closure by redefinition occurs when unresolved problems are redefined in a way that no longer poses issues for specific groups. Stabilization, on the other hand, involves achieving a consensus on the technology's standard form and meaning. Both are social processes influenced by negotiations and power dynamics among relevant social groups.

The significance of my research lies in its comprehensive approach to understanding not only the technological landscape of AR/VR but also the socio-cultural implications of their integration into education. As Bijker and Pinch highlight, "both science and technology are socially constructed cultures and… the boundary between them is a matter for social negotiation," and consequently, technological developments are deeply intertwined with economic, technical, and scientific considerations, which form a "seamless web" of interactions (Bijker & Pinch, 1987, page 11)**.** They assert that social environments influence the technical attributes of technology. This perspective challenges the notion of distinct knowledge categories and professional boundaries, advocating for an integrated view of technology development. Historical examples, such as Thomas Edison's notebooks and the founding ethos of Stone & Webster, illustrate the early recognition of this seamless integration across different functions of financing, engineering, and construction. These examples underscore the SCOT principle that technologies are shaped and defined through the social processes involving various actors and contexts. Technological frames exist not as attributes of systems or institutions but amongst actors, aligning with SCOT's perspective.

Applying the SCOT framework to the context of AR and VR in education reveals the intricate dynamics involved in the social construction of these immersive technologies. It emphasizes the socio-cultural dynamics that influence the development, adoption, and normalization of AR and VR in educational practices, offering a comprehensive perspective on the complex relationship between technology and society. In the early stages, AR and VR had multiple interpretations and potential applications. During the interpretive phase, different stakeholders contributed to the negotiation of AR/VR's meaning and purpose. Educators saw potential applications in enhancing classroom learning, healthcare professionals explored AR/VR for medical training, and the entertainment industry envisioned immersive gaming experiences. The interpretative flexibility allowed for a diverse range of applications to be considered.

Critics argue that SCOT overly focuses on agency, ignoring how social structures and power dynamics affect technology. They question SCOT's assumption of group equality and visibility in the design process, emphasizing the omission of power in shaping technological outcomes. In Klein & Kleinman (2002), the authors explore the social shaping of technology, emphasizing the need for incorporating structural concepts into understanding technological development. They critique the agency-centered approach used in the SCOT framework and argue that although it has significantly contributed to understanding technology, the theory has largely overlooked the influence of social structures. They propose that incorporating concepts from organizational sociology and political economy can enhance our understanding of how structural influences shape the design, development, and transformation of technology. The relative capacity of actors to shape technology is significantly influenced by structural factors such as the organization of industries, access to resources, and existing social norms and cultural values. Technological frames are shaped by cultural norms and historical patterns prevalent in wider society or among groups with similar social positions. By adding a structural dimension to the analysis of technological development, the authors to provide a better understanding of how technology is socially constructed and how structural factors can provide multiple opportunities for research in the STS field (Klein & Kleinmann, 2002). However, while acknowledging that structures themselves are socially constructed, Bijker, Hughes, and Pinch argue that their focus is on examining their impact rather than delving into their formation. This perspective allows for a deeper understanding of technology and its social context, challenging the notion that technology and society should be seen as indistinct entities (Bijker, Hughes, & Pinch, 1987).

As noted by Bijker, Hughes, and Pinch, technology's trajectory is significantly shaped by "relevant social groups" – a term they use to describe the various communities that interact with and interpret technology (Bijker, Hughes, & Pinch, 1987, page 30). Engineers, developers, and researchers envisioned AR and VR as tools for enhancing real-world experiences through digital overlays. However, relevant social groups, including educators, healthcare professionals, and entertainment industry stakeholders, had varied perspectives on how AR/VR should be designed and utilized. The interpretative flexibility allows for different educational stakeholders to contribute their perspectives on how AR and VR should be integrated into learning and teaching environments. As AR/VR technologies progressed, relevant social groups engaged in negotiations that led to closure and stabilization. Standards and conventions for AR/VR design emerged, influenced by the power dynamics and priorities of key actors. Closure occurred as certain features and functionalities became standardized across AR/VR applications, and stabilization happened as a consensus formed around how AR and VR should be integrated into various domains.

Educators may advocate for AR and VR applications that enhance student engagement and facilitate interactive learning experiences. Students, in turn, may have specific expectations regarding the usability and effectiveness of AR and VR tools in their educational journey. Policymakers may focus on the regulatory aspects and ethical considerations surrounding the use of immersive technologies in classrooms. The closure and stabilization phase involve reaching a consensus on the design, functionalities, and educational goals of AR and VR applications. This process is influenced by the power dynamics between educational institutions, technology developers, and policymakers. The standardization of certain features and the establishment of best practices contribute to the stabilization of AR and VR in education.

Innovative Educational Practices

VR programs adopted by higher education institutions have been enhancing engagement and improve student outcomes. My research investigates how AR and VR are practically applied in AEC education, including examples such as virtual simulations of construction sites, architectural design in virtual environments, and hands-on experiences facilitated by these technologies. In construction and civil engineering fields, creating a virtual and interactive experience system that helps teach students to plan the sequence of construction projects and using AR learning tools to understand use of equipment, processes, and operational safety exemplifies an effective application in the AEC industry. As part of visual-aided design tools, traditional 2D designs fail to display the complexity of a certain design in construction, so the use of AR/VR technologies can immerse students in a 3D environment enabling them to learn more actively. In Schroeder (1997), the author argues that the socio-technical development of VR systems is linked to the social dynamics within virtual worlds. It suggests that the popularity and sociability of virtual worlds influence the development of new VR systems and network capacities, highlighting the interplay between technology and social interaction.

A systematic literature review by van der Meer and co-authors analyzes 139 scientific research articles on VR for Collaborative Learning (CL) and creates a taxonomy to classify those articles based on trained skills and systems used. They found that skills developed are divided into five categories: cultural, domain-specific, learning, physical, and social skills. VR for CL provides various, interdisciplinary spaces for learning and collaboration. The authors contend that while VR is an efficient tool that engages learners and supports distance learning as well as remote collaboration, the field requires structured strategies to fully leverage VR technologies. Different educational sectors show interest in VRCL for its innovation potential and its ability to build communities, facilitate remote collaboration, and improve learners' social skills. Systems mainly used monitor-based VR with conventional controls like a keyboard and mouse, showing a general preference for non-Head-Mounted Displays (HMD) VR setups. The review suggests that VR can be highly effective for supporting CL, but it recommends that future research should explore differences between HMD and non-HMD VRCL in terms of affordances and challenges.

The innovative techniques in AR and VR being developed in an academic setting are beginning to influence the future practices within different fields, particularly as students adopt these advanced methods for VR in their design and prototypes. In their journal article, McGrath and co-authors, discuss UC Berkeley's creation of VR tools and simulations for architectural design. Professor Luisa Caldas and her team are transforming approaches to design by researching ways "to evolve the architectural design process, using virtual reality visualizations to provide an unprecedented sense of presence, scale, and depth of various stakeholders of building projects" (McGrath et. al, 2023). The adoption of methodologies from future studies has been beneficial, moving away from predictions full of speculation towards developing insights from various plausible futures. This method highlights the importance of strategic planning concerning accessibility, security, and privacy when integrating AR/VR technologies. The article outlines four scenarios, ranging from minimal change and adoption to scenarios requiring significant policy and infrastructure development in response to the fast-paced growth of the technologies. The future of these applications in higher education demands a detailed approach that anticipates varied technological impacts and prepares for the implementation of these emerging visualization mediums in a way that enhances educational experiences (McGrath et. al, 2023).

In Abuhammad et al. (2021), the authors present a study on the use of a VR gamified application designed to help students learn medicinal chemistry more effectively. Medicinal chemistry is crucial for pharmacists as understanding the spatial arrangement of molecules is crucial but is often seen as a difficult subject; traditional methods may fail to convey the three-dimensional nature of drug molecules effectively. The use of VR in education, particularly in complex fields like this, could enhance understanding by allowing students to interact with 3D models of molecules. The study introduces “MedChemVR,” a VR application that incorporates gamification to teach medicinal chemistry; students can visualize and manipulate 3D molecular structures. It “was developed using the Unity3D engine based on users’ requirements and in-depth medicinal chemists’ consultation,” and the developers performed a “preliminary evaluation of the Alpha version of the game with a focus group… [which] provided encouraging results, as well as enlightening feedback, which was utilized to improve the current version of the application” (Abuhammad et al., 2022). The application was designed for use with VR headsets and smartphones, making it accessible and easy to use. It includes features like a virtual classroom and various interactive modules focused on different classes of drugs. The effectiveness of MedChemVR was evaluated using a cohort of 41 pharmacy students. The evaluation involved students using the application and providing feedback through a questionnaire. The results were promising, showing that students found the VR application helpful for understanding complex molecular structures and reported that the gamification aspect made learning more enjoyable. Feedback suggested improvements such as better integration of structure-activity relationship data into the VR environment. The authors conclude that VR can significantly improve the learning experience in medicinal chemistry education. The use of VR allows for a more effective learning environment, which could potentially lead to better retention of knowledge and more positive attitudes towards the subject (Abuhammad et al., 2022).

Challenges and Equity in Technology Adoption

It is crucial to assess whether the industry is prepared to embrace and benefit from these technologies in terms of workforce readiness and skill development. Despite the technologies’ growing impact, challenges related to accessibility and affordability hinder widespread adoption, leading to disparities that disadvantage some students. Limited access can create significant differences in educational experiences, emphasizing the need to address challenges to provide equal learning opportunities. When considering the cost implications of implementing AR and VR solutions, it is important to explore open-source platforms to reduce licensing costs. To maximize these technology devices across students, implementing strategies for sharing the devices is vital.

As the research unfolds, it aims to bridge the gap between technical expertise and sociocultural insights. The STS analysis becomes a lens through which the research explores not only the technological advancements but also the societal shifts and cultural nuances that accompany the integration of these technologies impacting the future of learning in the digital age. The exploration of accessibility and affordability challenges acknowledges the socioeconomic disparities that might hinder the widespread adoption of these technologies, emphasizing the importance of equitable learning opportunities. For instance, by recognizing the challenges faced by community colleges due to systematic underfunding, the project transcends the boundaries of conventional engineering as it is a call to action, urging exploration into opensource AR and VR platforms and the implementation of strategies to maximize the use of these technologies across diverse student populations.

The AEC industry has witnessed transformative advancements in technology, but despite extensive research on the positive impacts of AR and VR on students' understanding, there is a critical gap in research on the applications of AR and VR in the industry. Limited attention has been given to systematically analyzing the affordances and limitations of immersive AR simulations. To bridge this gap, there is a need for a comprehensive quantification of the effectiveness of existing AR/VR applications in AEC education. One solution involves the development of a web-based platform that classifies applications based on functionalities, target audience, and educational objectives. This platform includes search functionalities, detailed application profiles, user reviews, and an online assessment tool to evaluate student learning outcomes. The major outcomes will be a catalog of AR and VR applications, a catalog with detailed descriptions, and performance metrics assessing skills improvement and practical knowledge application. Future work involves leveraging the platform's insights to guide educators, researchers, and institutions in selecting and implementing these technologies, thereby enhancing education quality in the AEC domain.

Internal workings of a technology become more hidden from view as it becomes normalized and integrated into everyday practices; users tend to focus on the technology's functionalities rather than its underlying complexities; students and educators interact with AR and VR applications without necessarily understanding the intricate technical details. As AR and VR technologies become integrated into mainstream educational practices, the focus shifts to the educational benefits and experiences facilitated by these technologies rather than their underlying complexities.

Each innovation in technology traces back to social processes and contexts that lay the foundation for its development and use. This stands in contrast to the technological determinist perspective, which views technology as the primary driver of societal change, often by referencing historical instances where technological advancements caused significant societal shifts. Technological determinism suggests that technologies inherently possess the power to shape societal structures, values, and beliefs. The SCOT theory provides a deep understanding of the successes and failures of technologies. In applying this framework to AR and VR technologies, the "relevant social groups can… be analyzed based on their interpretation of the five factors influencing the adoption or rejection of cross-reality technology [AR/VR/Mixed

Reality] in education…." (Varney & May, 2021, page 8). These factors include relative advantages, compatibility, complexity, trialability, and observability. This approach seeks to include these groups in the innovation process, aiming for a future-oriented development and adoption of technology in educational settings. Relative advantage refers to how cross-reality technologies offer benefits over traditional face-to-face teaching methods. Compatibility is the alignment of these technologies with personal preferences, values, and the existing educational framework; complexity deals with the challenge instructors face in learning and integrating these advanced tools into their teaching. Trialability can be defined as the ability to experiment with cross-reality technologies in teaching without disrupting established educational routines, and observability is how noticeable the implementation of these technologies is within the educational community (Varney & May, 2021).

Conclusion

The SCOT framework provides a robust analytical tool for understanding the social construction of technology, particularly in the case of AR and VR in education. By examining the interpretative flexibility, negotiations, closure, and context processes, we gain insights into how these immersive technologies evolve, gain acceptance, and become integral components of the educational landscape. Moreover, the historical and sociological insights provided by Bijker, Hughes, and Pinch emphasize the importance of transcending traditional dichotomies, such as science/technology and pure/applied, to appreciate the multifaceted nature of technological development. This holistic view resonates with the contemporary challenges of integrating AR and VR into education, highlighting the need for interdisciplinary approaches that consider the technical, social, and pedagogical dimensions.

This project stands as a testament to the multidisciplinary nature of contemporary challenges. It requires not only a deep understanding of technological complexities but also an ability to navigate the intricate intersections of technology, education, and society. By incorporating STS principles, this research aims to illuminate the broader societal implications of the adoption of AR and VR in education, considering factors such as economic disparities, cultural shifts, and policy implications. By emphasizing accessibility and affordability, the project reflects a commitment to equitable learning opportunities. As the educational landscape continues to evolve, this research seeks to provide valuable insights into shaping a future where learners of all backgrounds can benefit from the transformative power of AR and VR technologies. It envisions a future where education is not only technologically advanced but also inclusive, addressing societal challenges and fostering a more equitable and accessible learning environment.

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