Challenges and Strategies for Educational Virtual Reality: Results of an Expert-led Forum on 3D/VR Technologies across Academic Institutions

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ABSTRACT

Virtual reality (VR) is a rich visualization and analytic platform that furthers the library's mission of providing access to all forms of information and supporting pedagogy and scholarship across disciplines. Academic libraries are increasingly adopting VR technology for a variety of research and teaching purposes, which include providing enhanced access to digital collections, offering new research tools, and constructing new immersive learning environments for students. This trend suggests that positive technological innovation is flourishing in libraries, but there remains a lack of clear guidance in the library community on how to introduce these technologies in effective ways and make them sustainable within different types of institutions. In June 2018, the University of Oklahoma hosted the second of three forums on the use of 3D and VR for visualization and analysis in academic libraries, as part of the project Developing Library Strategy for 3D and Virtual Reality Collection Development and Reuse *(LIB3DVR), funded by a grant from the Institute of Museum and Library Services. This qualitative study invited experts from a range of disciplines and sectors to identify common challenges in the visualization and analysis of 3D data, and the management of VR programs, for the purpose of developing a national library strategy.*

INTRODUCTION

Virtual reality, 3D data, and other spatial technologies are being adopted in libraries as innovative and immersive tools for enhancing research and teaching.[1] VR provides a highly realistic, interactive visualization platform for engaging with 3D data, such as models produced from cultural heritage sites or medical imaging data, presenting many potential applications for a range of academic fields.[2] While these technologies are not new, they have become increasingly affordable, enabling widespread adoption beyond their traditional niches. For example, VR equipment has been studied in computer science departments for decades, but costs restricted use to large research labs.[3] Consumer-oriented VR headsets emerged in the late 1980s, but at a high

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price point and with many technical challenges, such as high latency in interactive graphics processing, they were ultimately unsuccessful in the consumer marketplace. Cheaper and technically superior mass-market VR headsets became widely available in 2016 with the release of the Oculus Rift and HTC Vive systems. VR is finally within the budgetary and technical means of libraries of various sizes to adopt and deploy.

At the same time, educators are developing new methods of crafting VR content. Decreasing costs of equipment associated with 3D data creation techniques, such as photogrammetry, laser scanning, and medical imaging (e.g., CT scanning), have encouraged their adoption outside of specialized fields. This content is increasingly used within immersive learning environments. Spatial data creation and visualization tools together can comprise a 3D/VR ecosystem that enables a range of research activities, including 3D scanning of cultural heritage artifacts, drone scanning of landscapes, interactive mapping, and data visualization, all of which can be viewed and analyzed in immersive VR.[4]

There is already evidence to suggest that VR has many academic benefits. While VR has not yet been proven to lead to better learning outcomes when compared with other educational media (indeed for learning certain types of facts, videos and lectures are often still more effective), it does offer other types of benefits. VR has been shown to lead to changes in student attitudes, such as increasing student engagement or self-efficacy.[5] Furthermore, research has shown the positive impact that 3D and VR visualization can have on analytic tasks for researchers, which indicates the benefit of having this type of equipment and support available through academic libraries.[6]

Despite decreasing costs and a growing understanding of the potential benefits of the technology, there is still concern in the library field about the cost and sustainability issues associated with bringing these types of technologies into the library. There are currently no standards or best practices in place for adopting 3D/VR, so institutions often have to develop ad hoc solutions, which wastes time by duplicating work already being done in other institutions and makes it difficult to share content due to a lack of interoperability standards.

To begin to address these challenges and aid in the maturation of 3D and VR as learning and research technologies, an interdisciplinary group of librarians from Virginia Tech, Indiana University, and the University of Oklahoma convened to develop a series of three national forums on this topic, funded by the Institute for Museum and Library Services (IMLS), as a project titled *Developing Library Strategy for 3D and Virtual Reality Collection Development and Reuse* (LIB3DVR).[7] Each forum was designed to cover a particular phase of the 3D/VR lifecycle within academic contexts. In June 2018, the second forum was held at the University of Oklahoma on the topic of *3D/VR Visualization and Analysis* and considered the following research questions:

RQ1: What are effective strategies for addressing common challenges faced by academic libraries as they implement 3D and VR programs?

RQ2: How are academic librarians using VR to support existing library services, such as curriculum development and access?

RQ3: How can the knowledge and resources of academic library–based 3D/VR programs be shared with other academic and information organizations, such as public libraries and regional higher-education institutions?

This paper presents the findings of the *3D/VR Visualization and Analysis Forum*, discusses the common challenges and strategies identified, and indicates key directions forward. The forum assembled invited experts representing academic libraries, commercial software companies, VR and visualization labs, and educational research centers for two days of closed-door discussions. The forum identified common challenges faced by a diverse range of stakeholders and institutions of various types and scales, synthesized strategies and practices discussed by forum participants as possible solutions to those challenges, and presented policies that participants are developing to support VR as a research and learning tool in their institutions.

In addition to convening experts in the field, a public forum was also held that brought together diverse stakeholders from the South Central United States library community to provide opportunities for engagement and knowledge sharing. Participants in the public forum represented local academic libraries, public libraries, public K-12 educators, commercial VR developers, and other academic programs. This enabled the cross-pollination of ideas and sharing of best practices for implementing VR in a range of contexts not represented by the invited experts. Including such a diverse group enabled the wider academic and library communities to benefit from the sharing of information that is otherwise often siloed or restricted to large institutions with substantial economic and knowledge resources.

LITERATURE REVIEW

A growing body of literature on VR has considered the technology's general benefits, explored its potential applications for research, presented methods of integrating VR into the classroom, defined some of the institutional challenges of adopting VR, and considered the use of VR for expanding library services.

The General Benefits of VR

While the science that informs the development of contemporary VR systems has its roots in nineteenth-century scientific perceptual research (and even further back we can see Rene Descartes' seventeenth-century theory of vision establishing the groundwork for contemporary VR systems development) it has been primarily within the last two decades that computer science and electrical engineering departments have defined the platform characteristics that reveal VR to be uniquely beneficial for working with complex 3D data.[8] Under controlled conditions, researchers have identified and tested the prevalence and impact of myriad "real-world" depth cues; benefits related to preservation of the embodied first-person viewer in a virtual environment; and the importance of increased viewing angles for engaging with what would traditionally be considered *cluttered* data sets.[9] Combined, this set of features allows for more efficient analysis of visual information, especially as related to activities where the user is expected to search, identify, describe, and compare subcomponents of complex, multivariate data sets.[10] Research has thus shown that VR is valuable because it presents information in context, at human scale, and in a way that is responsive to a wide range of body-centered interactions and representational characteristics that reproduce real-world interactions. These general benefits can be applied across academic disciplines and institutions.

Uses of VR in Research

The general benefits of VR that have been identified are now regularly employed in research capacities across the academy. VR and related 3D data-creation tools are being applied to fields such as digital humanities,[11] archaeology,[12] cultural heritage preservation,[13] medieval studies,[14] engineering,[15] biology and biodiversity research,[16] medicine,[17] and architecture.[18] In some cases, these approaches draw on the capabilities of 3D/VR to recreate immersive, high-fidelity experiences of real-world spaces, while in other cases, researchers are exploring the capabilities of VR to provide a platform for analyzing spatially oriented research data in the form of 3D models of cultural heritage artifacts and sites or visualizations of multivariate quantitative data.[19] In all of these cases, VR extends the capabilities of the human senses to engage with digital research data and scholarly outputs in ways that open new possibilities for discovery and analysis.

Integrating VR into the Classroom

Starting with work on *Second Life*, *Quest Atlantis*, and others, researchers have also studied the pedagogical potential of virtual worlds.[20] These early virtual worlds consisted of computer-generated 3D environments, but user engagement was limited to viewing them on 2D computer monitors and interacting via keyboard and mouse interfaces. Early virtual classrooms were designed and studied in the hope that they could effectively bring students and teachers together from across the world and enable them to engage with distant artifacts, locations, and people as part of the curriculum, and early research was concerned with how virtual worlds could emulate or expand on the benefits of traditional learning environments.[21] For example, Jeremy Bailenson has argued that VR is particularly well-suited for providing field trips to students, i.e., learning experiences that enable students to visit new places, and Chris Dede has identified the benefits and challenges of VR field trips.[22] One of the main challenges of this type of learning technology is the high cost of designing and building the virtual environments; however, as Bailenson points out, once they are created they can be endlessly replicated and shared, "enabling us to share educational opportunities with anyone who has an Internet connection and an HMD [head-mounted display]."[23]

With the increasing adoption by schools and libraries of VR equipment due to decreasing equipment costs, the focus has shifted to studying the pedagogical benefits of immersive VR experiences. These experiences place the user in an interactive, stereoscopic world, with interface controls modeled on intuitive embodied gestures and movements. VR has been shown to aid design and learning tasks in a range of fields, including design work in architecture classes[24] and anatomical instruction in medical schools.[25] These VR experiences augment, but do not replace, other forms of classroom learning, just as traditional field trips provide interactive learning experiences that contribute to formal classroom learning.

While these applications are impressive, the high cost of VR adoption leads to concern about evaluating the benefits of VR for learning. What types of benefits are valued and how do we evaluate those benefits in rigorous ways? Bailenson points out that VR may not facilitate factual knowledge acquisition better than other educational delivery methods; instead, it may have other benefits, such as increased student engagement, enthusiasm, and self-efficacy.[26] Indeed, Lischer-Katz et al. showed how a carefully designed course integration using VR could have a positive impact on undergraduate students' self-efficacy in regards to spatial analytic tasks and technology engagement.[27]

Mina Johnson-Glenberg studied two unique attributes of VR, "the sense of presence, and embodied affordances of gesture and manipulation in the 3rd dimension," and generated findings that supported the hypothesis that "when learners perform actions with agency and can manipulate content during learning, they are able to learn even very abstract content better than those who learn in a more passive and low embodied manner."[28] Schneider et al., Kuliga et al., and Pober and Cook have all documented the impact of VR on the process of architectural design.[29] In the case of Schneider et al., students engaged with digital and physical versions of the same facilities via virtual and real-world tours over the course of a semester. While students were critical of the digital surrogates' relative lack of atmospheric detail, they also communicated that "experiencing the 3D-model in real size helped to evaluate the design."[30] Similarly, Angulo successfully integrated VR into her undergraduate architecture coursework, resulting in a documented increase in term-project evaluation scores for those students who iterated on designs using a VR viewing tool.[31] These studies reflect the potential impact of VR across the design disciplines (e.g., architecture), where such tools are already being deployed in professional settings.[32]

Collectively, these studies indicate the likely benefits of VR in the classroom across disciplines, especially in fields where accurate perceptions of spatial characteristics—such as depth and scale—are critical to student (and professional) success. Additional work is necessary to develop and streamline pedagogical research instrumentation whereby easily applied metrics can be implemented by library and instructional staff to evaluate the effectiveness of VR on students and other users.

Institutional Experiences of Adopting VR

With the release of consumer-grade VR equipment, more and more institutions are considering the feasibility of adopting VR. As a result, case studies, practical strategies, and models for institutional deployment of VR are beginning to appear in the published literature.[33] For example, Austin Olney discusses the implementation of augmented reality (AR) systems at the White Plains Public Library in New York, and suggests that this endeavor is more easily accomplished by building off of existing VR capabilities and policies. In particular, logistical and legal concerns that had been addressed when previously deploying "public" VR (e.g., the signing of waivers before use) were useful for rapid deployment of AR.[34] Bohyun Kim offers practical considerations for the integration of VR systems into library makerspaces, assessing suitable VR hardware and software to support 3D-modeling activities at the University of Rhode Island Libraries.[35] Patterson and co-workers define five service models for integrating VR into libraries (see table 1 below).

Service Model	**Intended Use**
Open lab space	Walk-in
Closed lab space	Demonstrations, testing, and staging of new equipment
Flexible lab space	Reservable space and equipment for class or team use
Equipment checkout	Individual use
Developer kits (laptops and VR equipment)	For checkout to use in research, demonstrations, and presentations

Table 1. Library Service Models for VR.[36]

One of the major challenges faced by all institutions adopting VR is the concern over user comfort while using VR systems. As Steven LaValle suggests, "experiencing discomfort as a side effect of using VR systems has been the largest threat to widespread adoption of the technology over the past decades."[37] Fortunately, published best practices concerning baseline performance standards for consumer headsets and software design considerations have been well established in the literature, suggesting that those looking to adopt VR in institutional settings can do so by drawing on existing technical knowledge concerning how to ensure the relative comfort of VR users.[38] This combination of practical and technical considerations will undoubtedly further the adoption of VR across educational institutions worldwide.

The remainder of this article reports on the methodology and findings of this forum, which expand upon the benefits and challenges identified in the literature.

METHODS

The conveners assembled a two-and-a-half-day forum at the University of Oklahoma in Norman, Oklahoma, with fifteen expert participants in attendance. Participants were selected in consultation with an advisory board, with the intention of recruiting a diverse group of national experts in representative fields, including academic librarians, researchers from a variety of disciplines, and commercial game designers and software engineers.

The conveners used *nominal group technique* to generate research data for this study.[39] Nominal group technique is a consensus-building method for achieving general agreement on a topic through face-to-face small group discussions and it "empowers participants by providing an opportunity to have their voices heard and opinions considered by other members" in a structured format.[40] This method was adopted in order to reveal key challenges related to the visualization and analysis of 3D and VR data and strategies for designing and managing library programs to support these activities.

Data were generated through community note taking using Google Drive documents designated for each forum session. At the end of each discussion session, a group note taker summarized and presented the views of each small group to the wider forum. Both the raw, community notes and the summarized, facilitator notes were collected and analyzed. Notes produced from the smaller groups and from the larger group form the basis of the findings.

One discussion topic, "Course Integrations and Measuring Impact on Student Learning," was open to the public during the "public forum" portion of the forum on the afternoon of the second day (see the "Findings from the Public Forum" section, below). While these additional attendees were not given the opportunity to participate in the collaborative note taking, participants in the public forum provided anonymous responses to a set of questions on index cards that they submitted to the research team.

Data analysis consisted of grouping data from the community note-taking documents into higher-level categories based on the research questions and emergent themes, following an inductive analysis approach. A central part of the data analysis process involved moving from grouping specific examples of institutional practices and personal perspectives in order to link them to more general, community-wide phenomena. In this way, a set of shared challenges and strategies could be identified at the community level of analysis.

While there was a range of institutional and professional perspectives presented by the forum participants and the intention was to present a diverse set of perspectives on the topics covered in this forum, one limitation of this methodology is that it is limited to small groups of experts, which could potentially exclude other perspectives. The inclusion of the public forum, including more participants from a greater range of institutions, helped to mitigate this limitation. We validated these findings by disseminating drafts to participants and asking them to correct, clarify, or elaborate on the contents. The authors incorporated all participant feedback into a subsequent draft. This project was approved by the Institutional Review Board of the lead organizing institution, Virginia Tech.

FINDINGS

This section discusses the forum findings and aligns them with the project's research questions.

RQ1: What are effective strategies for addressing common challenges faced by academic libraries as they set out to implement 3D and VR programs?

Findings for research question 1 (RQ1) are broken down into three main areas: (1) human-centered design challenges, (2) initiating VR programs in libraries and schools, and (3) curriculum and research integration and assessment.

Human-Centered Design Challenges

Participants agreed that, in many ways, virtual reality is still an immature technology, which is reflected in shared experiences of forum participants, such as encountering simulator sickness and interface learning curves. As simulator sickness results from, among other things, a graphical rendering performance shortfall that leads to a disconnect between what the eyes and inner ear perceive, or an unnatural locomotive user interface (UI) decision on the part of content creators, the importance of graphics card and software selection (above and beyond their educational value) was emphasized.[41] Adding in-app spatial reference points—such as a virtual horizon line—was mentioned as a quick solution for the disorientation some users experience when engaging with virtual environments. Practical solutions were provided for some of the most common issues related to the academic use of VR, including providing ginger candy and personal mirrors, as well as defining reasonable time limits per person for in-headset time, to help with motion sickness as well as self-consciousness that follows the removal of a headset (i.e., mussed hair) that is experienced by some users, particularly students. Further, while not physiologically discomforting, instances of self-consciousness have been known to interfere with the educational effectiveness of virtual reality at the K-12 level, and methods for mitigating that experience—with the deployment of small mirrors, to check one's appearance after a headset session, for example—were discussed by forum participants.[42]

Most VR systems are able to provide both sitting and standing experiences. Standing experiences are particularly valuable insofar as full-body interface mechanisms allow users to engage their whole bodies in interacting with VR systems, which provides a close correspondence between a user's physical movements and their navigation of the virtual space. This decreases the learning curve of VR learning experiences, since the traditional alternatives—a sometimes tricky controller schema or command line interface—often require software or discipline specific training. In the case of seated VR systems, the system is able to accommodate users with disabilities. Not only are students, faculty, and staff with disabilities able to engage with VR content, but also the VR technology can provide heretofore impossible learning experiences by providing lifelike access to scenes that are physically inaccessible to them. While these possibilities are promising, participants agreed that further work needs to be performed to accommodate often overlooked barriers to accessibility. Examples of early techniques used to successfully address accessibility concerns include the mirroring of controller mappings to allow for use by either hand, the integration of accessible interfaces such as the Xbox Adaptive Controller, and the creation of open-source developer tools that can virtually adjust for a range of visual impairments.[43]

Regarding specific VR hardware currently available on the commercial market, participants were quick to point to common factors that limit the approachability, use, and scalability of university- or library-based virtual reality. One critical concern was the cost of VR equipment; at the high end, Oculus Rift, HTC Vive, and assorted Windows Mixed Reality headsets require a tethered connection to a dedicated personal computer (PC), and designated PCs must be outfitted with graphics cards that start at ~\$300 (US) and increase rapidly from there. To sustain the performance necessary for a stable and comfortable virtual experience to the end user, a \$500 graphics card coupled to another \$500-\$1,000 worth of computing hardware (e.g., CPU, motherboard, storage, monitor, etc.) is necessary, in addition to the purchase price of the VR headset. Cost-wise, high-end VR remains a prohibitively expensive endeavor outside of well-funded research institutions.

While cost was mentioned as a major cause for concern, the physical constraint to user movements due to the wiring that connects the VR headset to the PC impedes one of the primary features of the technology, positional tracking of user movement. The importance of *positional tracking*, the ability to track a user's headset and hand controllers along the six axes of motion as the user moves through physical space, means that interfacing with VR is ideally an intuitive, "natural," and immersive experience that can be easily disrupted if the user encounters cables or other restrictions to their movements. Fortunately, the major headset manufacturers mentioned above are starting to release more affordable, untethered, positionally tracked VR devices with increasing quality, which suggests that institutions ranging from K-12, to community colleges, to R1 research universities and academic libraries will soon be able to adopt immersive visualization technologies without encountering significant financial or ergonomic problems.[44]

Forum participants also noted that the same real-world fidelity that makes virtual reality an impressive learning platform can also produce harmful and disturbing effects. Indeed, many of the most popular VR titles are violent, action-oriented "first-person shooters," or multiplayer chat rooms in which very little attention is being paid to regulating abusive language. Moreover, there are some educational or training applications that, while culturally and politically sensitive, are nonetheless unsettling in a high-fidelity virtual environment. Disturbing places or objects can also negatively impact users; for example, phobia training applications in virtual reality, such as FearlessVR, might require academic institutions to deploy disclaimers prior to use at the risk of disruptive or damaging reactions from users (http://www.fearlessvr.com/).

Finally, forum participants discussed ways in which earlier design paradigms have subtly influenced the design of 3D/VR applications. Participants noted that while libraries and librarians might immediately assume that a books-on-the-shelf virtual library is a good way to invest time and development resources, the technology affords the means to interact with not just text-based materials (or the spines of books, in the case of browsing activities), but richly detailed "source material" (3D objects of study) as well. In the case of design principles, the entire body can be incorporated into wholly new search and discovery mechanisms that build on the best aspects of the library browsing experience while incorporating novel content types.

Initiating VR Programs in Libraries and Schools

Participants identified a variety of challenges associated with initiating VR programs in libraries and schools and a set of strategies for addressing these challenges. They discussed the challenges of developing curricula, the importance of management plans, the impact of particular institutional landscapes on the success or failure of 3D/VR initiatives, and offered some insight on the experiences of other information institutions, such as museums, that may be helpful to consider when developing broader strategies.

One emergent theme emphasized the challenges of developing curricula—specifically, customized 3D/VR teaching modules. Some participants noted that the expertise needed to develop these learning modules is unevenly distributed across the university, which makes it difficult to develop these critical teaching components. Furthermore, finding and funding technical expertise is a significant challenge, and participants discussed the difficulties in balancing the investment in untested technologies with the potential benefits of those same technologies. Untested technologies may be difficult to maintain and may require buy-in from administrators. Another challenge is the difficulty in getting researchers to share their project outcomes for use in instruction. Researchers who develop VR tools or content may not want to share the products of their labor because they perceive them to be integral parts of their research agendas, or they may feel that the products of their projects may be so customized that they will not be useable by other researchers. Finally, participants in the forum pointed to the general bottleneck of content creation for 3D and VR, which impacts the development of teaching curricula and the production of research-quality 3D data. More specifically, they noted that better workflows need to be developed in order to make it easier to create their own 3D models and to acquire and work with 3D models created by other researchers. Participants pointed out that a lack of easily accessible content will likely limit investment in VR programs and integration into curricula, which suggests that support for sharing content between and within institutions could be an important way of promoting the adoption of these new technologies.

Forum participants discussed how developing management plans for 3D/VR hosting spaces is essential to ensure successful initiation of VR programs. Participants offered a range of models for overseeing user engagement with VR equipment, including placing the equipment in a makerspace-like environment that was always monitored by staff; keeping the space locked with the option for users to request a key; as well as implementation in a fine arts space that has its own operating hours and security staff to oversee public engagement. Indeed, the question of staffing spaces emerged repeatedly throughout the proceedings, with the idea of using student staff from the host university or college as an effective and inexpensive means of overseeing 3D/VR spaces, assisting users, and troubleshooting technical issues that are typical of these new and emerging technologies. Students were also identified as potential content creators for those spaces and promoters of the 3D/VR programs to their peers.

The institutional landscape of the school hosting the 3D/VR program was also identified as an important factor that can impact 3D/VR adoption, since administrators can play a big part in helping or hindering VR implementation. Participants noted that they needed to explicitly justify the time and return on investment for VR in less supportive environments, which is not surprising given ever-tightening budgets across universities. Faculty support also impacts VR program initiation. While a handful of faculty members may be willing to superficially explore VR technology and try it out in one of their classes, wider adoption will require the provision of measurable student outcomes. However, the biggest challenge noted for getting faculty to support VR initiatives was convincing them that it could be useful for their research.

Participants from museums that are implementing VR or augmented reality (AR) technologies also offered some insight into institutional challenges of these technologies. Some museums are creating 3D scans of historical items, which raises a number of concerns about the accuracy of the models and how that impacts the meaning of the 3D models in the context of a museum's wider collecting mission. Museums want to create 3D content that is historically accurate, while at the same time being optimized for use in VR and AR applications. The biggest challenge identified is how to make the technology affordable while also maintaining its usefulness to communities of museum visitors. This aligns with concerns expressed by libraries, which also find balancing cost and usability to be a key concern.

Participants from across institutions offered strategies for addressing some of these challenges. First, participants noted that training sessions can provide an important introduction to VR for students and faculty that enables them to have a good initial experience and see the value of VR beyond its novelty. Without proper orientation, users could have an unpleasant initial experience, which could unnecessarily sour them on using VR in the future. Second, participants suggested several demonstration techniques for introducing a wide range of university and library community members to the new technology and exhibiting it in a positive light. "Road shows," i.e., taking the technology to other parts of campus or different communities, can be very useful for reaching users who may not otherwise come into the library to engage with emerging technologies. Library-hosted events, such as hackathons, workshops, and demonstrations can also help to develop interest among current library patrons. Providing mobile workstations for classroom use or individual patron checkout can also make the technology more accessible. These strategies suggest the importance of convincing potential users of the benefits of 3D/VR for their particular interests or research needs.

Curriculum and Research Integration and Assessment

Integrating 3D/VR technologies into established research and teaching conventions and workflows has proven to be a challenge, and all participants reported continued struggles to establish ways to assign credit to the creators of 3D/VR content, and methods of rigorously assessing the impact of this content on learning outcomes.

Regarding tenure and promotion concerns, it is not clear how faculty outside of technologically oriented or applied science disciplines might communicate and track their use of VR as a tool in their courses or research for inclusion in their tenure and promotion portfolios. Creating VR experiences represents a substantial investment of development resources and faculty time, and the experience itself—while distributable and citable—is not typically treated by the research community as a scholarly output. This is symptomatic of the relatively immature content ecosystem (i.e., a scarcity of educational VR software and scholarly 3D content), which necessitates either custom software development or forces researchers to use off-the-shelf tools that may comprise "blackboxed" data transformations or offer limited functionality.

To address this current lack of fully developed educational software and the necessity of assembling 3D/VR course modules piecemeal, participants concluded that the best place to start the integration process would be by establishing "first principles," or what is known for certain regarding the strengths and weaknesses of VR. Faculty members who want to include a 3D/VR component in their teaching or research agenda should familiarize themselves with the key benefits of the technology that transcend disciplines and that are supported by evidence-based assessment. Faculty should select task types for their learning activities that lend themselves to VR visualization, and deploy course (or research) content that, due to fragility, distance, rarity, or scale are relatively inaccessible.

Forum participants discussed how the benefits of 3D/VR in terms of a particular instructional goal or research initiative should be judiciously weighed against the relative cost of purchasing, installing, and maintaining what is still an immature, fast-changing set of interrelated content creation, visualization, and output (e.g., 3D printing) technologies. Moreover, once these technologies are deployed, and learning outcomes or research goals that align with the documented benefits of the technology are identified, assessment strategies should be deployed to evaluate the impact of these tools. Measuring performance, engagement (e.g., measuring time-on-task), comparative economic benefit (i.e., with respect to traditional course content delivery methods), and qualitative variables, such as impact on student self-efficacy, are all useful approaches for measuring the impact of VR in a research or teaching environment, and thereby may assist in justifying the expansion of these programs and tool sets.

RQ2: How are academic librarians using VR to support existing library services, such as curriculum development and access?

Participants discussed a number of applications for VR and related technologies that could help expand library services, including new ways of browsing and engaging with library resources, circulating VR equipment, and offering entirely new types of library services.

Some applications that were brought up included using AR to develop virtual books and book “trailers” that display promotional materials for each book as the patrons browse the stacks with their AR-enabled device. Using VR to engage with the materiality of books was also suggested. Participants gave examples of using VR to look closely at Medieval manuscripts, rare books, and artists books in order to observe their spatial properties, such as indentations, surface detail/topography, ink, and other material aspects.[45] Other participants suggested that VR could be used to compare and recontextualize library collections across geographies, placing the books in the contexts in which they were found and enabling comparative analysis of textual features. Participants also suggested that VR could be used as a platform for presenting numerical data, which could have applications for researchers who analyze data through already established visualization services at academic libraries. The discussion around expanding access using VR brought up the idea of libraries hosting 3D/VR collections, which could contain 3D scans and VR environments sourced from locally produced content and would be shared by 3D-scanning partners around the world.

One question that was raised was how to store the 3D content in a way that it could be easily transferred to VR systems for access. Participants from the University of Oklahoma discussed their work hosting multi-campus VR walkthroughs of 3D scans of historic sites (e.g., the arches of Palmyra, Syria), which offered an evocative example of how libraries can simultaneously provide access to technology, create and curate collections of scholarly 3D-scan data, and present expert-led events.[46] This shows how libraries hosting VR technologies can both be technological and intellectual partners in presenting 3D content to library patrons. Participants also pointed out how VR could be used to contribute to ongoing efforts in the library community to develop tools for linked open data and bibliometrics by creating new ways of visualizing networks of relationships between texts. These examples suggest that VR could be used as a multidimensional visualization platform that would visualize relationships between texts and areas of knowledge in rich and immersive ways, yielding new insights for librarians, library researchers, and other users.[47]

A circulation model of VR deployment was also discussed and found to be successful at several institutions. This typically followed a traditional “checkout” model of using the circulation desk to loan equipment for patron use for a limited time period. Some libraries check out all the VR pieces separately, while others are experimenting with full VR kits. Circulating VR equipment brings up a number of challenges, such as hygiene concerns, theft and loss of equipment, the cost of licensing and scaling up software purchases, and managing software accounts and updates. Adopting a circulation policy for VR may help to ensure the sustainability of the program by centralizing cost, risk, and point of access. However, centralization may not always be the most appropriate solution as it can turn off some faculty and discourage their interest in using it.

A final challenge of circulating VR hardware is the bottleneck of content creation, such that libraries find it difficult to provide new content for VR, which may make it difficult to sustain user interest over time. Some participants pointed out that without a game design curriculum or other creative programs on campus that have the capability of developing new content, users may lose interest, which would limit the success of a circulation-based model. If programs do not have access to the knowledge and tools necessary to develop VR content, it becomes difficult to expand services for development and pilot projects. It is therefore critical to form partnerships early on with content creators when developing VR programs.

RQ3: How can the knowledge and resources of academic, library-based 3D/VR programs be shared with other academic and information organizations, such as public libraries and regional higher-education institutions?

Based on participant discussions, several areas of concern were identified that need to be addressed in order for 3D/VR knowledge and resources to be shared with a broader range of institutions: methods for collaborating and coordinating across institutions; strategies for addressing development and hardware resource limitations; and addressing challenges to the widespread adoption of 3D/VR tools in higher education.

Methods for Collaborating and Coordinating Across Institutions

Collaboration and coordination across institutions was found to be important for ensuring that VR tools are made available to both large and small institutions. Few small colleges, cultural heritage institutions, or public K-12 school districts have the financial or technical resources to deploy educational VR at scale. The hardware and software used for educational VR require expertise—in the form of hardware setup, maintenance, administrative capabilities, and software development experience—represents a significant investment in labor (i.e., staffing overhead) and training on the part of research institutions, such as those participating in the forum. Forum participants agreed that, given the disproportionate concentration of expertise within higher education, initiatives should be undertaken to ensure that tools, workflows, training, and support are provided to organizations outside of academia. A consortium model was suggested as one formal mechanism for addressing this concern.

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Strategies for Addressing Development and Hardware Resource Limitations

In the case of software or content, Forum participants emphasized the value of open-source and open-access standards for facilitating the widespread distribution and use of educational VR content, especially for those without the development resources to create their own content. Participants suggested an open "app store" like ecosystem to assist in the distribution of this educational content across organizations. To aid in the successful integration of apps from a central database, participants discussed the prospect of supporting collaborators remotely, perhaps even from within VR, essentially training others on the software using the strengths of VR hardware. Finally, participants identified several large content-hosting platforms that host a variety of 3D assets relevant to education which might readily be deployed in VR without extensive development resources. A sandbox or open-ended viewing environment for loading and analyzing arbitrary sets of user-generated 3D models could be provided by the university or academic library, such that the end user would experience 3D-learning objects that were selected and deployed by local educators without the need for software development expertise.[48]

In contrast to the high-end VR workstations (e.g., Oculus Rift, HTC Vive, etc.), participants were quick to point to the relative affordability of smartphone-based VR solutions. These Google Cardboard–type implementations are especially promising, given the widespread adoption of smartphones with sufficient computing power to render interactive educational 3D content stereoscopically. In the case of Sketchfab, a commercial 3D-hosting platform, web-based 3D assets can be uploaded, collected, and accessed from any current smartphone device, and launched quickly into a stereoscopic viewing experience. In this way, more users at a wider variety of educational institutions can make use of some of the uniquely beneficial platform characteristics of VR (e.g., depth cues) without committing to the purchase of high-end VR workstations.

Addressing Challenges to the Widespread Adoption of 3D/VR Tools in Higher Education

Library technologists want to introduce VR to a wide audience of potential beneficiaries, yet this approach may cause faculty to dismiss such implementations as a novelty. Forum participants repeatedly discussed the importance of involving faculty in implementations of VR tools and spaces that have academic value. Participants noted how the uptake of 3D/VR technologies can be thwarted when faculty are disinterested or are not well-informed about the potential uses of 3D/VR technologies.

Forum participants noted that university faculty who want to incorporate 3D/VR technologies are faced with many of the same challenges encountered by smaller educational organizations, including lack of guidance on setup and maintenance, administrative pushback, and high cost. Participants agreed that academic libraries should play a critical role in the hosting and administration of these systems. Deployment of 3D/VR technologies in academic libraries would provide a central resource that could be used by many departments, including those fields that may lack the resources to invest in their own equipment. Moreover, since librarians already act as research and instructional collaborators with faculty, those relationships can be drawn upon when adopting VR, and showcasing faculty engagement helps to demonstrate the academic value of 3D/VR technologies for library and university administrators.

Further Strategies for Collaborating Across Organizations

Interinstitutional collaboration was put forward as a means to begin addressing the challenges facing both universities and smaller educational organizations seeking to implement 3D/VR programs. Participants agreed that it was incumbent upon the larger universities or institutions to provide open access to their VR software projects and provide the mentorship and training necessary to successfully deploy these applications for use by smaller institutions. Forum participants suggest that, in some cases, this will require a physical visit to a collaborator's location and live demonstrations of tools and techniques. Alternatively, a showcase or summit event could be hosted by large institutions for the purpose of demonstrating 3D/VR technologies to a number of small institutions. At such events, during site visits, or within VR-based training sessions, best practices and the results of empirical research on the efficacy of 3D/VR could be communicated to smaller organizations.

One such institution type, public libraries, was discussed in relation to the potential value of collaborative outreach. Even with limited budgets, public libraries are trying to bring 3D/VR technology to their patrons. They would benefit from becoming strong collaborators with local universities and colleges. For example, summer programming at public libraries could be organized to effectively distribute the software, standards, best practices, and workflows being pioneered at the university level. Forum participants suggested a "hand me down" program for donating earlier generation headset hardware, which is replaced quite frequently and at great expense, but is typically still functional. In this case, smaller organizations would benefit from surplus equipment funded by research grant money or donor contribution, both of which are less common at the public-library level. Along with the open-access software and 3D-asset ecosystems discussed above, this sharing of hardware and knowledge would increase the impact of 3D/VR technologies across multiple organizations and institutions.

Findings from the Public Forum

The public portion of the forum consisted of a half-day, afternoon session attended by local stakeholders from other academic libraries, public schools, public libraries, and other institutions in Oklahoma, Texas, Kansas, and Arkansas. They were invited to attend and engage in discussions with the invited experts on the topics of 3D/VR in relation to smaller institutions, such as public K-12 schools and public libraries. The following section reports on findings from that session, drawing on a set of 38 anonymously completed notecards that participants filled out during the public forum and returned to the project team. For these notecard responses, participants were asked to answer the following three questions:

1. What challenges do small- and medium-sized, public-facing institutions face when implementing VR?
2. How can large institutions support small- and medium-sized institutions who are starting to adopt 3D/VR?
3. What options are there for public libraries or K-12 to participate in 3D/VR workflows?

The following sections summarize those responses and the key themes from the public forum discussion.

Challenges Faced by Small- and Medium-Sized Institutions

Public forum participants identified challenges related to cost (including equipment, maintenance, and staffing), content creation, and faculty/administrator buy-in as the top concerns facing small- to medium-sized public institutions looking to deploy educational VR. Regarding cost, it was clear that budgets for innovative, unproven technology that may become quickly obsolete were oftentimes nonexistent, and those local VR champions who sought to install such technology faced pushback from administrators who do not understand the technology and are focused on measurable returns on investment rather than exploratory offerings. Finally, staffing was a challenge identified and shared by multiple public forum participants. To hire, train, and support skilled staff members who are expected to keep abreast of ongoing developments of a still young technology such as VR requires a sustainable investment from administrators.

Participants noted that even having skilled staff in place and access to the necessary equipment, the success of a given VR deployment was not guaranteed. One potential bottleneck identified by public forum participants was VR content creation. Due to the relative immaturity of the VR software marketplace and its associated disorganization, public-forum participants described focusing their efforts on supporting local content-creation efforts by students, faculty, and staff. Beyond recognizing the need to hire and support costly development workers, public-forum participants also noted how the preservation and further distribution of locally produced VR content require skills and training beyond their level of expertise. Oftentimes, these small- to medium-sized public institutions have a single staff member, who may not have all of the required technical skills, tasked with deploying and developing VR content, which limits the local impact of this potentially transformative educational technology.

Finally, multiple public-forum participants identified the need to garner faculty buy-in as a recurring challenge. Oftentimes faculty do not know about the technology or have a limited understanding of it. To overcome this, public-forum participants noted that a demonstration of VR's value is critical. They suggested that this demonstration might be accomplished in partnership with larger educational institutions (e.g., universities), whose own staff, content, and expertise could be leveraged to best communicate the value of VR to local administrators and faculty.

Ways Larger Institutions Can Support Smaller Ones

Beyond assisting small- to medium-sized public institutions in demonstrating the value of VR for local faculty and administrators, public-forum attendees suggested that the continued development and distribution of open-source VR software, providing help with setup and maintenance issues, and engaging in formal knowledge distribution activities—in the form of conferences, consortia, and grant partnership—would streamline the adoption of VR by these smaller public institutions. Public-forum participants also expressed a desire to engage with the research outputs of larger institutions that focused on the efficacy of VR, which may be useful for working with local faculty and administrators.

Software sharing was specifically identified as a way that larger institutions could support the early efforts of small- to medium-sized institutions as they set out to deploy and integrate VR. Participants were careful to note that additional support, in the form of training and troubleshooting, was equally important to the distribution of the software itself. The affordability of VR software was described as a particularly important issue by a number of participants, hence the focus on open-source solutions by the group.

Predicting inevitable hardware and software failures, public-forum participants communicated that onsite support by VR experts from larger institutions would be ideal. Participants noted that, while knowledge sharing is important, guidance on how to set up a specific system sometimes requires onsite support. Fortunately, there are novel support mechanisms supported by the technology itself, with public-forum participants suggesting that experts could be "brought in" to provide support in the virtual environment itself. In this case, a multiplayer VR experience similar to those demonstrated by the content developers in attendance could function as an interactive learning platform for the distribution of information and would even provide training on the technology.

Ways Public Libraries and K-12 Schools Can Participate in 3D/VR

The size and diversity of the public library and K-12 user communities were reflected in the feedback provided by public forum participants concerning ways in which these types of institutions can participate in VR. Participants suggested that within public libraries, focus groups that represent different ages, physical ability levels, and socioeconomic backgrounds of library users can be recruited to test and refine VR offerings. In this way, the wider public can be introduced to VR technologies and made aware of their benefits.

The potential for K-12 students to assist in the VR-content development process, which could have the added benefit of helping students develop valuable technical skills, was also mentioned as a way that these institutions could participate. This programming need not start out as a formal curriculum, participants suggested, but rather as an afterschool program, taking the form of a "modern day A.V. club," as one participant suggested. Public-forum participants identified the need for compensation or incentive programs for those adolescents in public libraries who are wishing to contribute to the content creation process.

Overall, participants in the public forum provided positive feedback about their experience at the event: "Very useful indeed. I learned a lot," wrote one participant. "It's nice to hear perspectives of those working in academia and to share our own perspectives . . . " wrote another public-forum participant. A third participant was enthusiastic about the future, writing: "I love the idea of libraries being partners." These responses indicate the importance of collaboration between small and large institutions and the value of these types of public forums for sharing knowledge in this field.

SUMMARY OF FINDINGS & DISCUSSION

The findings drawn from the discussions and presentations at the forum offer a broad view of the current concerns of this diverse community involved in implementing 3D/VR in academic institutions for the purposes of education and research. The range of stakeholder groups is expansive and demonstrates a growing interest in immersive visualization technology across many fields and institution types.

By reviewing previous literature in conjunction with the group discussion findings, we can identify and summarize a set of common challenges facing libraries and other information institutions that are implementing 3D/VR technologies. In the following section, we describe these challenges or considerations identified for each topic and point towards possible strategies or directions forward for addressing them.

Initiating VR Programs in Libraries and Schools

The main challenges facing libraries and schools as they initiate VR programs include developing interest and awareness for the emerging technology among faculty, students, and administrators; locating necessary expertise in VR within their communities when knowledge is unevenly distributed; getting enough buy-in from administrators to support the allocation of necessary resources; encouraging researchers to share their projects and research outputs for the benefit of the larger community; and overcoming the bottleneck of VR content creation as a limiting factor on institutional investment. From the findings we can identify a set of strategies to begin to address these issues, including:

- Utilize demonstration techniques to generate student and faculty interest in VR (e.g., "road shows" and library-hosted events, such as hackathons, workshops, and demonstrations).
- Develop replicable workflows that can be implemented by a variety of stakeholders.
- Establish management plans for 3D/VR hosting spaces that include using student labor for overseeing VR technology spaces and content creation.
- Develop and validate metrics for evaluating the impact of VR technologies in order to provide evidence for faculty and administrators that VR is worth their time and investment.

Integrating VR into Research and Teaching

From the findings, we can also identify a number of challenges related to integrating VR into research and teaching. One of the major challenges in this area is related to the research community not valuing VR projects as scholarly or pedagogical outputs. Because of this, faculty members are typically reluctant to invest their time and resources into developing VR curricula if it will not contribute to their tenure and promotion portfolios. Related to that problem is the issue of assigning credit or attribution to 3D/VR learning objects when they may be developed by teams, which can discourage sharing and limit reuse of VR learning modules. Finally, because of a lack of metrics for measuring the impact of 3D/VR on student learning, it has been hard for faculty to rationalize integrating what is sometimes perceived as unproven technology into their classes. Determining which metrics to use has pedagogical as well as economic implications, since without metrics, it becomes difficult to rationalize the expense of 3D/VR to institutional administrators. Participants did not have strategies for addressing all of these challenges, but offered the following suggestions:

- Design VR course integrations that take advantage of the particular access and analytic characteristics of VR technologies.
- Weigh instructional goals with the cost of VR equipment and development time.
- Develop assessment strategies and define metrics for evaluating the impact of VR learning activities on students.

Expanding the Role of the Library with VR

The group agreed that libraries are ideal places for hosting 3D/VR equipment, services, and support because they are often centrally located in their communities and they can potentially help by centralizing the risk and cost of untested technologies. Participants identified a number of new techniques for utilizing the benefits of 3D/VR to expand existing library services, such as offering new ways of browsing and engaging with existing library resources, enabling the development of 3D-based digital collections and curated exhibitions and events that draw from those collections, and adding VR-visualization equipment as another piece of digital technology that libraries can circulate to support the various uses of the range of patrons interested in this technology. Again, although there was no lack of big ideas in regards to how 3D/VR could expand library services, the biggest challenges for libraries adopting 3D/VR into existing services was still a lack of verified educational content, which confirms the dire need to share 3D/VR content within institutions and across the wider community. Without platforms for sharing 3D/VR content and the appropriate institutional and disciplinary incentives to do so, 3D/VR is unlikely to be adopted broadly and the range of exciting new applications will not be realized beyond niche projects.

Collaborating and Coordinating Across Institutions

Based on the findings drawn from both the expert-led and the public portions of the forum, it is clear that collaboration and coordination across institutions is essential for making 3D/VR a widely successful educational and research tool, because it can enable the sharing of resources with a range of smaller institutions that would otherwise not be able to adopt the technology on their own. Supporting this exchange will require providing faculty at larger institutions with the necessary tools and incentives to support that sharing, which is an area in which participants agreed that academic libraries could serve as the needed source for technical knowledge and equipment. In summary, participants identified the following approaches for supporting efforts at collaborating and supporting smaller institutions and expanding access to underserved communities:

- Larger institutions should provide tools, workflows, training, and support through on-site visits.
- Universities should partner with public libraries, since they can be hubs for providing access to communities that would otherwise not have the opportunity to engage with 3D/VR outside of academic communities.
- Use open-source and open-access standards and content, including an open “app store” ecosystem of 3D/VR content.
- Use existing databases of free 3D content.
- Use affordable smartphone-based VR applications when more expensive VR systems are not feasible.

These findings contribute to current discussions in the field of library innovation that consider how libraries can adopt and sustain emerging technologies, such as VR and 3D technologies.[49]

We have identified a set of common challenges and possible strategies for integrating 3D/VR programs into libraries and educational institutions, but additional research is required in this area to produce more detailed workflows for a range of institutional types to follow. There are inherent limitations to any specification, since every context has its own specific requirements for 3D/VR implementation, but as these findings suggest, there are common challenges that can be addressed in systematic and generalizable ways. These findings offer some examples of this, but additional data collection is necessary to focus on some of the key areas that are still developing.

CONCLUSION

The overriding theme across the findings from the forum is the importance of interinstitutional and interdisciplinary collaboration. Confirming what we had assumed going into this project, it is clear that many of the challenges of 3D/VR can only be solved through systematic and concerted effort across multiple stakeholder groups. 3D/VR is not limited to a niche area. As we can see from the range of participants and applications, it has broad transformative potential and is becoming increasingly mainstream in many contexts. This suggests the importance of addressing these challenges through additional forums and working groups to generate standards and best practices that can be applied across the growing 3D/VR community. Such guidance needs to be specific enough that they can offer practical benefit to stakeholder groups of varying capacities, but flexible enough to be useful for a range of applications and disciplinary practices.

While the findings from the forum suggest a variety of techniques and strategies for addressing the challenges identified, there is still much work that needs to be done to establish standards and best practices, generate institutional support, and enact change within disciplinary cultures in order to better support these communities. In particular, the following areas require further inquiry:

- Develop validated metrics for evaluating the impact of 3D/VR, from pedagogical, research, and institutional perspectives.
- Develop guidelines and tools for supporting users with disabilities.
- Support smaller institutions in initiating and supporting 3D/VR projects.
- Find ways to educate skeptical disciplines about the value of research and teaching that uses 3D/VR.
- Develop tools for supporting 3D/VR throughout the research or educational lifecycle, including:
  - project management and documentation tools;
  - universal 3D viewers that integrate with VR equipment and 3D repositories;
  - sustainable, preservation-quality file formats for 3D and VR; and
  - open platforms for hosting 3D/VR content.

There are a number of other projects that are addressing some of these lingering challenges within the field of 3D and VR research and teaching, including *Community Standards for 3D Data Preservation (CS3DP)*, an IMLS-funded project that is using a series of meetings and working groups to develop community-sanctioned standards for preserving 3D data in academic contexts (http://gis.wustl.edu/dgs/cs3dp/); *Building for Tomorrow*, another IMLS-funded project that is developing guidelines for preserving 3D models in the fields of architecture, design, architectural archives, and architectural history (https://projects.iq.harvard.edu/buildingtomorrow/home); the Smithsonian Institute's *3D Digitization Program*, which is developing workflows and metadata guidelines for a variety of 3D creation processes (https://3d.si.edu/); and the Library of Congress's *Born to Be 3D* initiative, which has started convening experts in the field to look at the preservation challenges of "born digital" 3D data, including CAD models, GIS data, etc. (https://www.loc.gov/preservation/digital/meetings/b2b3d/b2b3d2018.html). The LIB3DVR project team will continue to collaborate with members of these project teams to ensure that knowledge is shared and that any standards and best practices that are developed for 3D/VR visualization and analysis take into consideration the findings from this Forum. The project team is confident that through these initiatives, useful standards and best practices will emerge to assist educators, researchers, librarians, technologists, and other information professionals address the complex challenges of implementing 3D/VR visualization and analysis for scholarly and pedagogical purposes in their institutions.

NOTES

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