Examining Low-Cost Virtual Reality for Learning in Low-Resource Environments

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ABSTRACT

We describe our experiences co-designing low-cost Virtual Reality-augmented learning experiences with and for an after-school learning center in Mumbai, India that caters to low-income children from neighboring communities. In partnership with 5 staff members and 16 students at the center, we spent 7 weeks co-designing, piloting, and iterating on VR lessons targeting 28 academic topics over a total of 15 classroom sessions. We found that VR was used to demonstrate real-world phenomena, illustrate abstract concepts, compare and contrast places in the curriculum against virtual landmarks, and motivate students. Most importantly, VR's representational fidelity appeared to arouse students' curiosity, leading them to ask more questions that reflected deeper engagement with the topic.

Author Keywords

Virtual Reality; Learning; Google Expeditions; HCI4D

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION

Highly immersive virtual environments accessed using specialized Virtual Reality (VR) hardware like Head Mounted Displays have shown improved learning outcomes [9, 14, 18], increased confidence [21, 22], and positive behavior change [2]. However, most prior research has taken place in experimental conditions and controlled laboratory settings that often involve expensive VR equipment and room facilities. At the same time, the consumer market is increasingly being flooded with affordable VR technologies such as low-cost viewers; unofficial versions of the Google Cardboard viewer [3] may be purchased for under US$8. These viewers can be used with lower-cost smartphones to access a growing base of VR applications and content (including VR-enabled games, 360-degree videos/panoramas) produced by third-party developers/hobbyists, making VR more accessible than before.

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These developments make it increasingly viable for VR to be used in everyday educational settings such as the classroom. Given the reality of limited budgets for public education, for instance, VR could be used to take students on virtual tours of global sites of educational significance without leaving the classroom. This could be impactful for students from lower-income households with limited educational opportunities. To realize this opportunity, however, more contextual research is needed to understand the users' contexts—especially what happens when VR is introduced into these contexts—as a first step in replicating the above outcomes.

In this paper, we report on a 7-week study at a learning center that caters to children from urban slums in Mumbai (India). Our research contribution is to discover what happens in a low-resource educational context when VR is introduced. How do users in such a setting feel about VR? How do they plan to use VR to advance their educational goals? What are the challenges when VR is introduced into the class? What are the workarounds and solutions that users come up with?

RELATED WORK

This paper builds on the small body of research on low-cost VR for education. The only relevant study we found was [17], which was a preliminary experiment with rural students in India. Five students were randomly assigned to learn about Fort Golconda using VR, while another five were assigned to learn about the fort in a traditional classroom. The early results suggested that students in the VR condition performed better on spatial awareness (*e.g., "How big is the Golcanda Fort in relation to your school?"*), while students in the traditional teaching condition performed better on factual questions (*e.g., "Who built the Golcanda Fort?"*). The study also reported usability findings with respect to the VR experience, but its scope did not include the broader adoption issues encountered when VR was integrated into existing lessons.

Our work extends a long line of research on mobile phones [1, 10, 12], laptops [4, 16], desktop computers [15], and other technologies (*e.g.,* [5, 6]) for education in developing regions. What is unique about VR, however, is that the positive outcomes cited in our introduction are often attributed to "presence," that is, the user's subjective sense that s/he is present in an alternate reality [19] that multi-sensory VR technologies are optimized to induce. Finally, in response to Toyama's caution that *"there are no technology shortcuts to good education"* [20], recent meta-analyses of over 150 randomized and quasi-experimental studies in developing countries have

found positive educational outcomes associated with technology introduced under the right conditions [11, 13].

TIMELINE AND METHODS

We conducted our research at an after-school learning center in Powai, a suburb near Mumbai, inhabited by migrants from all over India. The center was founded 10 years ago by a doctor whose clinic was in the community, with the goal of providing free basic education to children from disadvantaged backgrounds. Classes take place in the morning (and afternoon) to cater to students attending public schools in the afternoon (and morning). These schools follow state curricula. Students receive lessons on topics covered in school, supplementary topics (not in curriculum), and computer literacy.

At the time of our study, the center had 7 administrative staff, 12 teachers, 5 volunteers and 125 students (grades 4 to 12). Teachers were full-time employees who taught and managed entire classes. They were paid hourly based on their qualifications (high school diploma to a Bachelor of Education) and teaching experience (1 to 10 years). Volunteers were students from a nearby college who helped by providing one-on-one tutoring to students needing academic support. The center's facilities included 4 classrooms, one lab with 5 desktop computers and 1 printer, a Wi-Fi network, and 5 tablets. Two classrooms each contained a wall-mounted television and a desktop whose screen is projected onto the TV.

We worked with the same participants through all phases of our study—a teacher called Meera (pseudonym), all 6th-graders (8 girls and 1 boy), and all 7th-graders (5 girls and 2 boys). Meera was responsible for teaching 6th- and 7th-graders General Knowledge, Geography, History and Science. She has a high school diploma and has been a teacher for 5 years. We recruited her on the founder's recommendation, who commended Meera for her commitment to innovating on her teaching approaches. All fieldwork was conducted by Aditya, the first author, a native speaker of Hindi–the medium of instruction at the center. The data was examined by all authors and analyzed inductively to iterate on key themes. Fieldwork took place as follows:

Phase 1: Formative work over 2 weeks in December 2015 and 2 weeks in June 2016. This phase included 60 hours of participant-observations over 12 visits; 20 semi-structured interviews with 15 students, teachers, and staff; 2 focus groups with parents and teachers; and 2 brainstorms with teachers and staff. The goals were to gain a deep, situated understanding of the center's learning activities, as well as establish the level of trust and rapport with stakeholders such that they see value in committing an adequate amount of time to co-designing and piloting VR-augmented lessons with us. In total, we observed 39 (and 33) class sessions among the 6th-graders (and 7th-graders) that Meera taught.

Phase 2: Co-designing the VR-augmented lessons lasted 1 week in June 2016, during which we worked intensively with Meera to co-design lessons that incorporated VR. In total, we co-designed VR-augmented lessons that spanned 6 lesson units, that can be further broken down into 28 academic topics for 15 classroom sessions (approx. 13 hours).

The VR technology we chose was Google Expeditions [8]. At the time of our study, it was the most inexpensive off-the-shelf option, worked under low bandwidth, and had a comprehensive suite of educational content (250 VR tours of landforms, natural ecosystems, landmarks, museums and cities). Expeditions runs on tablets and smartphones over a Wi-Fi access point that does not need connection to the Internet. To give the teacher more information about each tour when planning and teaching a lesson, the system allows her to view a write-up on each tour. She uses her tablet or phone as a remote control to select a tour, which is then downloaded wirelessly from her device to every student's smartphone. A student then views this tour virtually on her phone's screen. If she has a Cardboard [3], she can insert her phone into the viewer to experience the tour immersively as a 360-degree panorama, such that what she sees adjusts naturally as she turns her head.

Phase 3: Piloting the VR-augmented lessons with Meera over 2 weeks in July 2016 in 15 class sessions (6 with 6th-graders only, 6 with 7th-graders, and 3 with both). After every lesson, we iterated with Meera on her VR plans for subsequent classes. The Expeditions virtual tours were accessed using a Nexus 9 tablet (teacher), 12 Cardboard viewers (students), and 12 Nexus 4 smartphones (students). The phones were salvaged from recycling centers across Mumbai.

FINDINGS

As one 7th-grade girl shared, students appeared to look forward to going to the center everyday:

> *"All the actual learning happens only here [at the center]! In school, the teacher writes on the board, and we write it down in our notebooks. No explanation or anything else is given."*

The Classroom Before VR

Due to the founder's enthusiasm to innovate on teaching and learning, this center was well supported to integrate technology into the curriculum compared to many schools that cater to low-resource communities. The teachers and volunteers ensured the tablets were fully charged at all times, while other devices such as TVs were in working condition.

Meera engaged in whole-class instruction in which she lectured on specific topics, interspersed with moments when the entire class was a large discussion group. When lecturing, she used the TV or tablet to stream YouTube video lectures related to the topic she was teaching, at least twice every week, in order to complement her explanations. Similarly, she paused each lecture at least once to Google for images (*e.g.,* Mount Everest) related to the lesson (*e.g.,* Geography), in order to have students visualize what they were taught with the tablets. Instead of performing all the Google searches herself, she sometimes had students play a more active role in their learning, by asking them to search for images specific to the lesson. For example, Meera had students Google for an image of India's map, after which she explained the three seas shown on the map that surround the Indian peninsula. At other times, she assigned students to play a related educational game on the tablet. Due to limited hardware, each tablet was shared by 2-3 students. No student seemed to have

difficulty with Google searches on the tablets. In transitioning from lecture to class discussion, whenever Meera asked a question, one or two students would raise their hand(s) to answer the question or share an opinion with the class.

The First VR Class

Meera was enthusiastic about teaching using Expeditions after Aditya demonstrated how the VR solution worked: *"I think this sounds very interesting! I am very excited to try this out. Just help me out the first couple of times? I don't feel very confident using this entirely* [on my own] *yet."* She believed her students could experience highly immersive, rich content they have not encountered before. She decided to use Expeditions to take her 6th- and 7th-graders on a tour of the "7 wonders of the world" since she had covered these in their General Knowledge class only a day ago.

Meera enlisted four volunteers to help charge the phones before class, setup the phones in the Cardboard viewers and distribute them during class, and help students with any difficulties encountered during class. It turned out that at least one volunteer was more than enthusiastic to help, since he had already seen advertisements about Cardboard and had asked Aditya to help introduce it to the center, even before Aditya had broached the subject of partnering to explore how VR could be integrated into the center's lessons:

> *"You've heard of the Google Cardboard, right? ... Can you help me find resources online where I can build my own [Cardboard viewer]? I'll definitely work on building my own [viewer], so that we can start using this on our own [at the center] too."*

It was often necessary for students to share the viewers since the phones ran out of battery in the middle of class. Meera converted these situations into opportunities for small-group learning by having students share their viewers and discuss what they saw, similar to how she had them share the above tablets. The 6th- and 7th-graders loved the highly immersive VR experience. They exclaimed loudly in awe each time Meera directed them to a new Point of Interest in the virtual tour. During class discussion, there appeared to be a more active buzz in class, with many more students volunteering more frequently to answer Meera's questions. Most importantly, students asked questions that reflected a higher degree of curiosity, which seemed to result from immersive VR's ability to allow them to see the wonders of the world more vividly for themselves:

- *"Why is the Colosseum shaped like that? I can see its walls are broken in many places. What happened?"*
- *"Why did they bring this huge statue of Christ on top of this hill [in Brazil]? Why did they do this? Did/do the people worship this statue?"*

Meera was encouraged by the initial response:

> *"I loved working with [Expeditions] - especially because of the students' reactions. Did you see them? I want to use this for 10-15 minutes everyday, especially for... General Knowledge... I want to take out 10 minutes at the end of... class ... and show them random sites and explain it to them. I really like that [the Expeditions app has] write-ups for me to read and get some background information about [the landmark], so I can explain to the students what they are seeing."*

On the flip side, many students were afraid to hold the Cardboard because they thought the viewer and smartphone were expensive, and would be unable to compensate for any damages. Meera and the volunteers made a conscious effort to allay this fear. Based on accounts by others who had shared Cardboard viewers among lower-income users in India, we were more concerned about an outbreak if a student has an eye infection and spread it by sharing her viewer with other students. Fortunately, no infection broke out, possibly because we took necessary precautions (*e.g.,* cleaning the viewers with a hand sanitizer before each use).

Planning To Teach More VR Classes

Although the founder supported the pilot and allowed Meera to have her lessons timetable "slide" by a week to accommodate the VR experience, Meera decided to proceed according to the sequence and schedule she had originally planned prior to the pilot. In working with Meera to identify the best ways to integrate VR into her lessons, we took a first pass at all the virtual tours bundled with Expeditions so she could familiarize herself with them. In the process, she identified 60 tours applicable to the state curriculum. This was followed by a second pass, during which Meera reviewed her lessons timetable for the next 2 weeks to identify topics that students in previous years were less excited about. She eventually identified 28 topics that belonged to the following 6 units:

- Man-made Monuments Around The World (6th- and 7th-grade General Knowledge)
- World History (6th- and 7th-grade History)
- The Harappan Civilization (6th-grade History)
- The Living World (6th-grade Science)
- Economic, Social, and Cultural Life (7th-grade History)
- Propagation of Light (7th-grade Science)

Next, she identified relevant tours that could potentially make the above topics more engaging. This process was time-consuming and involved extensive brainstorming between her and Aditya. Despite Google's continuing investment to create more Expeditions virtual tours relevant to the Indian context, at the time of the study, there were few tours on Indian landmarks featured in the curriculum. Likewise, there were fewer tours relevant to the refraction of light.

The VR-augmented lesson that Meera designed for a typical class started with a recap of what students had learned in a previous lesson. This was followed by going on 1-3 relevant Expeditions tours, and a class discussion that aimed to connect the VR experience to the lesson's topics. In total, Meera's lessons exhibited four different ways in which VR could be integrated with the curriculum:

1. To demonstrate actual real-world phenomenon, *e.g.,* anatomy to show how body parts work. This was applicable when there was VR content exactly on these topics.
2. To illustrate abstract concepts in the syllabus, *e.g.,* a virtual tour of Varanasi, a trading center, as an example to illustrate economic concepts such as trade and economic growth. This worked for content that could be appropriated to illustrate topics that the content may not have been originally designed to target.
3. To compare and contrast, *e.g.,* a lesson on the history of the Harappan civilization could use the Egypt tour when no tour exists for the former. Students were asked to compare and contrast the reasons for the decline of the two civilizations, their arts and culture, their systems of government, as well as other high-level themes and curricula strands found in the state curriculum. This activity format was applicable when the content and target lesson shared the above high-level curricula strands.
4. To arouse interest, *e.g.,* a tour of South Africa's Kruger National Park to show a diversity of animals living in the wild. This worked for content related to a topic even if the content did not directly address the learning goals.

Subsequent VR Classes

Most importantly, compared to her classes before the introduction of VR, Meera pointed out that the number of questions and the length of the class discussion time had increased. Similar to her first class with VR, she also observed that students continued to ask questions that were deeper in nature. Before using VR, questions were more superficial (*e.g., "What does soil erosion mean?"*, *"How do you spell 'hippopotamus' in English?"*). By contrast, after she started using VR for teaching, students asked questions that reflected a deeper level of curiosity, engagement, and reflection on lesson topics (*e.g., "Why was the Great Wall of China built in the first place?"*). Students related what they saw in the virtual tours (*e.g.* Mount Everest) to their lesson topics (*e.g.*, where Everest is situated on India's map).

Students made positive comments about their VR experience:

- *"We saw the tallest building in Dubai* [*i.e.,* the Burj Khalifa] *– it was so beautiful! And the drawings and paintings inside the wall of the church were so beautiful and nice. It is so much cooler than watching on TV – this is more real."*
- *"It* [the Expeditions virtual tour] *is so amazing! I really like the 3D feeling I get. The pictures are so clear and clean – and beautiful. It feels like I am actually there and the place is all around me."*
- *"When you* [Meera] *showed us the giraffe and the polar bears, and oh my God those sharks! I got scared—they looked so real! . . . Tigers! I would love to stand near the animals . . . Also, show us more things that we do not know of—like new places in the world."*
- *"It feels like it is right in front of us, and like we are standing right there. Like I can stretch my hand and touch the shark! I felt so scared but excited afterwards."*

While some of the positive responses to VR seemed to be on account of the property of "presence" often associated with highly immersive VR experiences [19], the photorealism and representational fidelity of the places, animals, and objects in the virtual environments appeared to be stronger contributors.

Lastly, students assumed ownership of the VR experience, which was essential for long-term viability of using VR in the classroom. For example, a few students helped to recharge the phone batteries and set up the Cardboards before each class. Other students took responsibility for maintaining the viewers. This included spending a weekend to craft three viewers out of plain cardboard and other recycled materials, once they learned that they could make viewers on their own. They encountered setbacks initially on one morning, but exhibited persistence throughout the rest of an afternoon, which included going online to search for tutorials.

CONCLUSION

After VR was introduced into the classroom, students appeared to ask questions that reflected a deeper level of engagement with the topics targeted. This outcome seemed to be facilitated by the affordance of representational fidelity that highly immersive VR has, such that students can view places and objects in virtual tours with a higher degree of photorealism and fidelity compared to non-VR technologies. It appeared that this fidelity also enabled students to take a closer, more vivid look at virtual places and objects that induced deeper curiosity and questioning.

While representational fidelity has been cited as a unique affordance of VR [7], most prior work has studied this affordance in the context of less immersive virtual environments that were accessed using regular computers without specialized VR hardware. More research is needed to understand why fidelity may promote learning, and how fidelity can enhance immersive VR experiences to support learning. More research is also needed to understand deeper underlying reasons for the excitement to use VR, possibly by comparing the use of VR to that of high-resolution videos and/or images.

Finally, VR was used to demonstrate real-world phenomena, illustrate abstract concepts, compare and contrast places in the curriculum against virtual landmarks, and motivate students. To some extent, the final three lesson formats were devised as a workaround when little VR content could be found to directly targeted the intended lessons. Since developing good learning content that aligns with curricular needs is expensive and cumbersome, as a middle ground, third-party developers could explore how to design content for appropriation into new lesson contexts. For instance, in their existing content offerings, they could aim to have more substantial coverage of the higher-level themes and curricula strands present in major curricula standards. This could enable their content to be more easily incorporated into "compare and contrast" lessons, for example.

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REFERENCES

1. Elba del Carmen Valderrama Bahamondez, Christian Winkler, and Albrecht Schmidt. 2011. Utilizing multimedia capabilities of mobile phones to support teaching in schools in rural panama.. In *CHI*. 935–944.
2. Jeremy N Bailenson and Kathryn Y Segovia. 2010. Virtual doppelgangers: Psychological effects of avatars who ignore their owners. In *Online worlds: Convergence of the real and the virtual*. Springer, 175–186.
3. Cardboard 2016. Google Cardboard Homepage. **https://vr.google.com/cardboard/**. (2016).
4. Ruy Cervantes, Mark Warschauer, Bonnie Nardi, and Nithya Sambasivan. 2011. Infrastructures for low-cost laptop use in Mexican schools. In *Proceedings of the SIGCHI conference on human factors in computing systems*. ACM, 945–954.
5. Andrew Cross, Mydhili Bayyapunedi, Dilip Ravindran, Edward Cutrell, and William Thies. 2014. VidWiki: enabling the crowd to improve the legibility of online educational videos. In *Proceedings of the 17th ACM conference on Computer supported cooperative work & social computing*. ACM, 1167–1175.
6. Andrew Cross, Edward Cutrell, and William Thies. 2012. Low-cost audience polling using computer vision. In *Proceedings of the 25th annual ACM symposium on User interface software and technology*. ACM, 45–54.
7. Barney Dalgarno and Mark JW Lee. 2010. What are the learning affordances of 3-D virtual environments? *British Journal of Educational Technology* 41, 1 (2010), 10–32.
8. Expeditions by Google 2016. Google Expeditions - Google for Education. **https://www.google.com/edu/expeditions/**. (2016).
9. Fatima Gutierrez, Jennifer Pierce, Victor Vergara, Robert Coulter, Linda Saland, Thomas P Caudell, Timothy E Goldsmith, and Dale C Alverson. 2007. The effect of degree of immersion upon learning performance in virtual reality simulations for medical education. *Medicine Meets Virtual Reality 15: in vivo, in vitro, in silico: Designing the Next in Medicine* 125 (2007), 155.
10. Matthew Kam, Akhil Mathur, Anuj Kumar, and John Canny. 2009. Designing digital games for rural children: a study of traditional village games in India. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. ACM, 31–40.
11. Shari Krishnaratne, Howard White, and Ella Carpenter. 2013. Quality education for all children? What works in education in developing countries. *New Delhi: International Initiative for Impact Evaluation (3ie), Working Paper* 20 (2013).
12. Anuj Kumar, Anuj Tewari, Geeta Shroff, Deepti Chittamuru, Matthew Kam, and John Canny. 2010. An exploratory study of unsupervised mobile learning in rural India. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 743–752.
13. Patrick J McEwan. 2015. Improving Learning in Primary Schools of Developing Countries A Meta-Analysis of Randomized Experiments. *Review of Educational Research* 85, 3 (2015), 353–394.
14. Tassos A Mikropoulos. 2006. Presence: a unique characteristic in educational virtual environments. *Virtual Reality* 10, 3-4 (2006), 197–206.
15. Udai Singh Pawar, Joyojeet Pal, Rahul Gupta, and Kentaro Toyama. 2007. Multiple mice for retention tasks in disadvantaged schools. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. ACM, 1581–1590.
16. Ismael Peña-López. 2010. From Laptops to Competences: Bridging the Digital Divide in Education. *RUSC. Universities and Knowledge Society Journal* 7, 1 (2010).
17. Fabin Rasheed, Prasad Onkar, and Marisha Narula. 2015. Immersive Virtual Reality to Enhance the Spatial Awareness of Students. In *Proceedings of the 7th International Conference on HCI, IndiaHCI 2015 (IndiaHCI'15)*. ACM, New York, NY, USA, 154–160. DOI:**http://dx.doi.org/10.1145/2835966.2836288**
18. Maria Roussos, Andrew Johnson, Thomas Moher, Jason Leigh, Christina Vasilakis, and Craig Barnes. 1999. Learning and building together in an immersive virtual world. *Presence: Teleoperators and Virtual Environments* 8, 3 (1999), 247–263.
19. Mel Slater and Sylvia Wilbur. 1997. A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments. *Presence: Teleoperators and virtual environments* 6, 6 (1997), 603–616.
20. Kentaro Toyama. 2011. There are no technology shortcuts to good education. *Educational Technology Debate* 8 (2011).
21. Nick Yee and Jeremy Bailenson. 2007. The Proteus effect: The effect of transformed self-representation on behavior. *Human communication research* 33, 3 (2007), 271–290.
22. Nick Yee, Jeremy N Bailenson, and Nicolas Ducheneaut. 2009. The Proteus effect: Implications of transformed digital self-representation on online and offline behavior. *Communication Research* (2009).