Empeiría[*]: Powering Future Education Training Systems with Device Agnostic Web-VR Apps

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Abstract. This paper presents *Empeiría*, which uses cutting-edge technologies and novel virtual reality systems to enhance future in-class education training. *Empeiría* incorporates JavaScript, WebGL, WebVR, and powerful web graphics engines like Babylon.js to create immersive training experiences. It demonstrates a useful application of computer science concepts and increases the dissemination of edge technologies across academic disciplines. Most importantly, *Empeiría* improves education technology and professional training through the creation of two major software products; an immersive experience editing system (*Empeiría-E*) and an immersive experience viewing system (*Empeiría-V*). We show how these virtual reality systems can lead to more effective training and improve our understanding of trainees.

Keywords: Virtual Reality, Babylon.js, Education Technology, Computing Methodologies, Virtual reality, Human-centered Computing

1 Introduction

Videos of classroom instruction and students' learning are commonplace among tools used to train future and practicing teachers, and similar patterns of video use are found among other professions [1]. The use of such videos has demonstrated positive effects on teachers' professional knowledge. Despite the demonstrably positive effects and usefulness of videos for professional practice, there is a need to improve how well such videos represent the context of teaching. Recently, this desire has led to the introduction of 360-videos in teacher training [2]–[4]. Whereas what is viewable in a standard video is pre-selected by the videographer, 360-video format better reflects the teaching context by recording a spherical view of the classroom scenario and allowing viewers to adjust the field-of-view. In [2], authors found that this differentiation increases the perceptual capacity of a video, or what is perceivable in a recording. Put another way, teacher- trainees who view 360-videos are able to notice more professionally relevant

[*] *Empeiría* – Greek for "Experience"

events and describe these events in more detail than their counterparts who watch a standard video of the same lesson. By increasing the perceptual capacity of a video, 360-videos increase trainees' perceived immersion in the experience, thus better approximating a trainee's sense of observing the classroom in-person.

Prior studies of 360-videos describe recording from a single camera perspective [3], [4]. However, this doesn't accurately approximate reality as teachers seldomly stand in one place for an entire lesson, but instead move about the room. Thus, we sought to develop a multi-perspective, 360-video editing, viewing and sharing platform to further improve teacher training and more broadly, professional development; while also overcoming barriers to entry like technical expertise or coding experience.

Empeiría allows for members of a profession, that lacks technical expertise or coding experience to create immersive, 360-video training experiences. Its mission is to enable educators to improve their professional knowledge by immersive training simulations. To that end, *Empeiría* allows educators to easily create immersive training sessions, edit and augment them with annotations, distribute them to trainees, and collect data about the trainees' interaction and performance.

This paper will explore *Empeiría*'s creation and the creation of novel, virtual reality, systems from a computer scientist's perspective. It will show how WebVR, WebGL, JavaScript, and powerful graphics engines like Babylon.js (BJS) [5]. can be integrated to create convincing, immersive experiences and training simulations. It will make a case for device-agnostic web apps, modern web technology, and the utility of highly accessible products. *Empeiría* is an open framework for creating virtual reality, immersive professional development simulations, viewing those immersive sessions, and analyzing trainee's performance. *Empeiría* is device agnostic and works with most commodity head mounted displays (HMDs). The only requirement being a compatible web browser. This is made possible through our approach of leveraging web technology, WebVR and BJS to provide highly accessible service.

Empeiría has two major components; a simulation editor and a simulation viewer. The editor, *Empeiría-E*, allows educators to produce training simulations for distribution. The viewer, *Empeiría-V*, allows trainees to experience a production simulation and records quantitative data about their experience like which annotations they interact with, the camera perspectives they choose to use, their device's orientation over time, and their gaze vector. To better understand how these components work, it's important to conceptualize the educator's workflow.

The educator's workflow begins with the deployment of multiple 360-video-cameras throughout various locations in a classroom. Next, the educator begins recording the in-class session, from multiple perspectives. Once finished recording, the educator uploads the session's recordings to *Empeiría* and begins the editing/production process. During the editing process educators augment the scene and enhance the session with virtual annotations that guide trainees involvement and professional noticing. After editing and augmentation, the simulation is distributed to trainees for consumption and improvement of their professional knowledge. Once distributed, the trainees enter the immersive experience from within *Empeiría-V*, the viewing system. As trainees experience the simulations, annotations they interact with, camera perspectives they choose to use, device's orientation overtime, and gaze vector are recorded (among other things) in a remote database-system for post-hoc analysis. This post-hoc analysis reveals trends, behaviors, and other insights that help educators, trainers, and researchers answer key questions.

Beyond the technical features, there exists several additional functional requirements such as the product needs to be widely accessible (device agnostic, cross platform), low cost to entry (open source), and easy to use (good design). The software product needs to be responsive, have good performance, and high quality of experience (QoE). It needs a simple user interface and a simple immersive experience. We expect that educators have limited exposure to novel technologies and limited technical expertise, as well as restricted device offerings and potential budget concerns.

Empeiría's significance is its demonstration of a novel application of WebVR and device agnostic web applications to the education technology space. It defines an open framework for editing 360-videos, adding annotations, creating immersive learning experiences, and distributing those experiences to users. It demonstrates how existing works can be pulled together and synthesizes to create a powerful software product which gives post-hoc insights to educators and researchers. Additionally, its supports the creation of better educators and, in turn, more prepared students. The implication being that more prepared students results in a better and more capable American community. Furthermore, it promotes the use of BJS and WebVR which will likely power the future of virtual reality on the web, cross platform functionality, and overcome major hurdles in the dissemination and popularization of virtual reality.

2 Related Work

As a multifaceted and cross-discipline project, that includes human-computer-interaction (HCI), this work relates many works. *Human-Computer Interaction* when describing its comprehensive account of the multidisciplinary field HCI: "it balances the technical and cognitive issues re-quired for understanding the subtle interplay between people and computers, particularly in emerging fields like multimedia and virtual environments." and a subtle interplay it is, there's so much going on it's hard to reconcile everything and for brevity, we won't attempt to [6]. The remaining portion of this section will describe the most critically relevant aspects of HCI as it overlaps with VR, web technology, and eye tracking.

In regards to the computer science literature: it touches upon HCI, virtual reality, 360-videos, eye tracking and the broad disciplines of web technology. In this case, web technologies are modern JavaScript and specifications like WebVR, and BJS. In regards to educational aspects like training and education technology; it touches upon teaching, practice, reflection, recall, cognitive load, physiological response, and the potential of immersive experiences to increase professional noticing and improve training.

In any case, there is an abundance of related work on these topics. However, there's limited work on building open and comprehensive frameworks (like ours). There's even less work that synthesizes many technologies to meet specific concerns in education technology. Note that, there's even less work (likely none) on building these comprehensive frameworks as device agnostic web apps powered by libraries like BJS, utilizing WebGL, and supporting WebVR. Attributes which we believe are important to the accessibility, dissemination, and support of virtual reality on the web. This is likely what our contribution to the science is, formulating an open framework and demonstrating a novel use of WebVR. The remainder of this section will be split into sub-sections that explore relevant work as major topics.

2.1 Virtual Reality

There's general research about virtual reality in the classroom [7]. There is work on combining virtual reality with mobile eye tracking to create experimental environments [8]. And, actually this process is so well established that we mention it here as a major consideration of our project, although it hasn't been fully integrated into our framework. In the case of [3], the objective is to study and experiment with shoppers as they move through and visually investigate a virtual store, but this is similar to what we are doing with education trainees as we study their navigation of the immersive classroom experience. There's work on real time gaze mapping in virtual environments, which is an interest of ours, and there's research on people getting sick from simulations, but findings that they are less prone to sickness when actively engaging with the scene/content, which is something we experienced [9], [10].

Cinematic Virtual Experience. In this case, the user is not experiencing a featured film, but instead a professional development/training media. The approaches and work are still applicable to our interest. There's research on increasing recall within these cinematic virtual experiences via gaze direction and flickering [11]. The primary candidate of these methodologies being publishers of educational or corporate training content (very similar to our stakeholders) [11]. There's work on guiding the users attention in 360-videos using videography and filmography techniques [12]. There's work on the effect of camera height, actor behavior, and viewer position on the user's experience of 360-videos [13]. All of these are considerations as we interact with our open framework and the creation of training simulations.

2.2 Web Technology

Device Agnostic Web Apps. There's work on WebVR, BJS, and the device agnostic possibilities of VR [14]. There's research on leveraging HTML5 and WebGL for simulation based Training in the U.S. Military to improve experience accessibility and dissemination, which again, is very similar to our interests [15]. There's a case study on a WebVR device agnostic web application for immersive museum exhibitions [16]. There's work on immersive 360-degree social experiences which is similar to our product, in that it uses modern web technologies [17]. There's research on making device agnostic products with web5VR framework, which is again similar to our approach [18]. However, none of these works provide an open framework for immersive experience augmentation, creation, dissemination, and trainee analysis. We consider them, but they aren't adequate to meet our needs.

BabylonJS. We chose to use BJS for our framework for reasons which are omitted here, but further explained in the System Design section. There's some relevant support for BJS as a performant and superior WebGL framework which is something we agree with and we used to make our selection [19]. Here's another example of BJS powering a WebVR application that is device agnostic, cross platform, only requires a browser [20]. However, again it doesn't suit our specific purpose.

WebVR. This article makes a good case for furthering the adoption of virtual reality with WebVR content, cross platform approaches, and HMDs, focusing on accessibility and compatibility with a broad-band of devices [21]. We consider some WebVR specific dev approaches, like an agile development approach to WebVR applications called "Roll & Raid". It attempts to improve the development of WebVR applications through lower cost, higher efficiency, stronger adaptiveness, and easier team management [22]. Here we find the most applicable case for WebVR, a product called AmbeintVR; it has a great description of why WebVR is so useful for device agnosticism, cross platformality. It is one of the most relevant papers to our work as it makes a similar case for WebVR [23]. Web-based GIS application for real-time interaction of underground infrastructure through virtual reality (uses BJS) [24]. Building a WebVR 360 viewer for the experiment, similar to what we are doing, but again lacks the full open framework aspect and immersive professional training [25]. These works set a precedence, but each lack what's required of *Empeiría*.

3 Research Significance

This section describes, in clear terms, why we our research is significant. It reiterates some of the previous points which we alluded to and further down the research significance into several major perspectives.

3.1 Computer Scientist's Perspective

It demonstrates a novel WebVR application that is device agnostic and highly accessible. It defines an open framework for editing 360-videos, adding annotations, creating immersive professional training experiences, and distributing them to users. To the best of our knowledge, no other works introduce a comprehensive open framework that fulfills these specific immersive training, education technology, requirements. Note that, our open framework might be used for any other type of training simulation [15]. Furthermore it demonstrates how existing technology can be synthesized to create new capabilities, and a rich and capable software product that provides stakeholders with a broad array of insights.

3.2 Educator's Perspective

For the educator, our work is significant because it improves the immersive training experience, trainees' detail recognition, and the perceptual capacity of 360-videos. While making these improvements, it reduces barriers to entry like technical expertise and cost. Furthermore, it leads to the creation of better educators, and in turn more prepared students.

3.3 Researcher's Perspective

It builds upon existing research works and demonstrates how valuable data can be collected from virtual reality experiences. It speaks to how that data might be visualized and interpreted. Unlike previous works, it uses a novel logging schema that suits our specific education technology stakeholder. Ultimately, It defines how edge technologies can help us better understand the user's experience and our training simulations. Where previous works falter, we bring the benefits of a comprehensive open framework.

4 System Design

There are several approaches to building virtual reality experiences: native-platform-dependent, native-cross-platform, or non-native platform-independent web app. However, these approaches require users to download, install and update dedicated applications. This complicates the user's life, but also further complicates developers' lives. Developers must go through and comply with app stores, appease publishers, and overcome learning curves associated with shifting between development platforms.

With the capabilities of modern web browsers, features that previously attracted developers to native applications are becoming dually available for web apps. Furthermore, with the creation of Progress Web Applications (PWAs) and accelerated WebGL rendering, web apps gain the offline-capabilities and performant features that made native development appealing. Considering this and the increasing capabilities of web browsers, building VR applications using HTML5, WebGL and JavaScript has become a seriously appealing development alternative.

Instead of going through restrictive app stores, these immersive experiences can be deploy directly to users, from the web. In this way, adoption-friction is reduced and users can explore immersive apps with nothing more than a web browser. Moreover, application updates and changes are adopted immediately and pushed to users independent of store-publishers. For these reasons, virtual reality on the web has great promise, long legs, and is our chosen approach to the ed-tech problem.

The ability to access rich VR experiences without a download or install is naturally appealing. For a developer to be able to create VR content for the masses using simple, affordable tools is obviously fantastic. Best of all, powerful and versatile libraries like BJS are fueling innovation and creating regularity in the development-process. For example, BJS' video-dome and VR-experience-helper allowed us to rapidly produce our immersive framework which can be distributed to phones, laptops, and HMDs. However, amidst the potential are limitations which provide challenges for us and other new WebVR techniques.

To tackle our project's mandates we create an open and extensible framework for immersive training experiences, that utilizes the modern web approach. We create a

WebVR, WebGL, 360-video, and JavaScript framework which enables users to create annotated video immersive experiences and disseminate those immersive sessions for other users to consume. We primarily utilize BJS to interface with WebGL and create WebVR experiences. In addition, our app aims to report and profile trainees' behavior as they interact with the immersive scene. The result is a highly accessible, modular, and low-cost platform for educators. *Empeiría* is able to discover information about trainees' behavior, experience, and expertise. It can integrate with any data visualization and insight pipeline that quantifies performance metrics and makes complex information easily digestible. Fig. 1 shows a high-level system architecture of *Empeiría*.

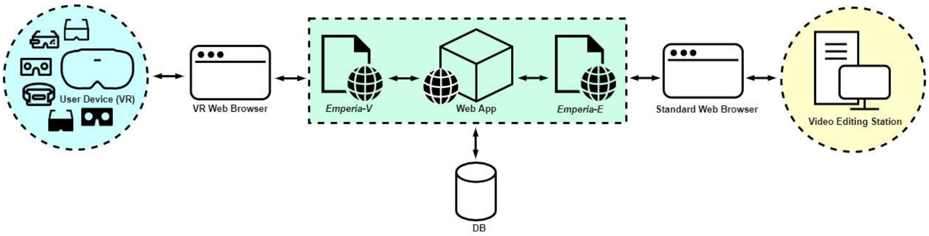

Fig. 1. The system architecture of *Empeiría*.

4.1 Immersive Canvas Architecture

Foundational to *Empeiría* are its immersive canvases. The immersive canvases are where viewing sessions happen and editing sessions take place. The major architectural components of an immersive experience canvas are shown in Fig 2. *Empeiría-E* has six canvases which allow multi-perspective simulation editing and creation. *Empeiría-V* has one canvas which allows a viewer to experience an immersive session. The canvases utilize BJS Video Domes and HTML-Canvas to render 360-videos on *Empeiría-V* and *Empeiría-E*. Other functionality like VR experience helper and annotation manager are also built upon BJS. Whenever a WebVR experience takes place, there is an immersive canvas involved.

Fig. 2. The Immersive Canvas Architecture

The engine drives the virtual scene's rendering. The scene is an object which contains a camera, lighting, video dome, vr-helper, and annotation management panel. In general, most components belong to the scene. A constant loop renders it in conjunction with a BJS engine.

4.2 Empeiría-E: The Editor

The first module of *Empeiría* is *Empeiría-E*, a multi perspective tool. It allows educators to view and edit six camera perspectives simultaneously. They can edit the videos independently or as a collection. The editor provides the user with the capability of controlling and editing videos, and the capability of adding and controlling annotations. Fig. 3 shows an example of the 360-Video Editor (*Empeiría-E*).

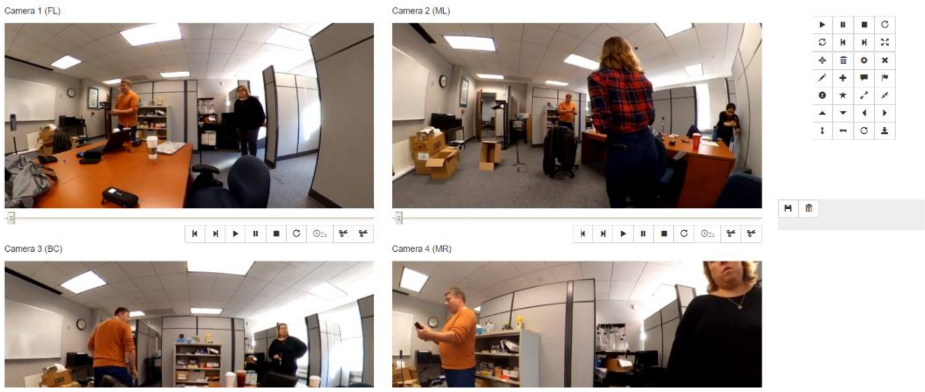

Fig. 3. Screenshot of *Empeiría-E*

Video. Each canvas (video feed) has a control bar and a slide bar which allows the session editor to skip backwards, skip forwards, play, pause, stop, restart the video, show the current time of the video, or cut video clips. There is also a more powerful master-toolbar on the right side of the page which has universal video controls like play-all, pause-all, jump-all, sync-all, etc. that allow the user to reconfigure the videos and create consistency between camera perspectives. This master-toolbar allows the user to select an active canvas via a DOM-tree inspecting tool [26]. Once an active canvas is selected, the user can set the play time of all other videos to be the same as the play time of the video of the active canvas, i.e. synchronize the play time of all other videos with the play time of the video of the active canvas. Also the user can toggle the active canvas to become full screen or normal size.

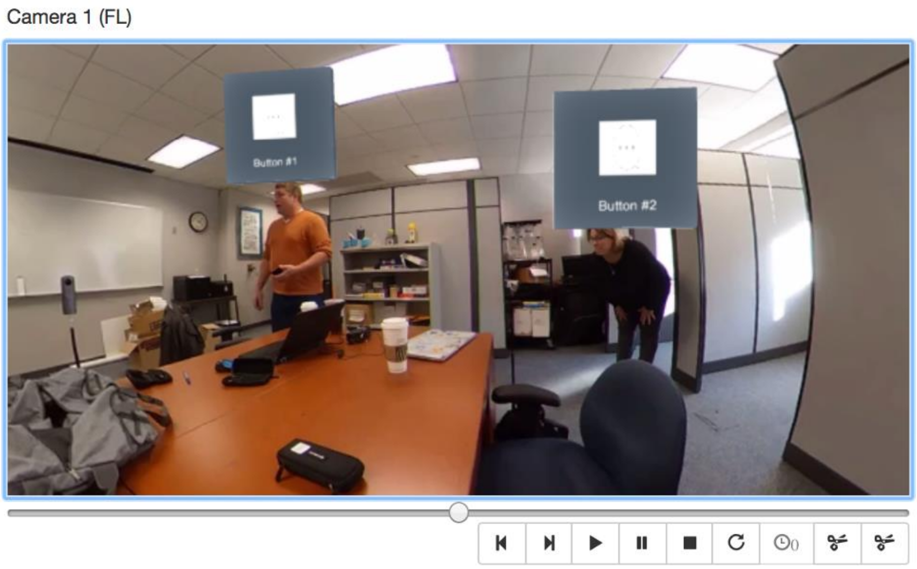

Fig. 4. Screenshot of video annotations.

The user is able to cut video clips using the button in the control bar under each canvas. After the user selects a start time and an end time of a video, the video clip during selected time will be automatically cut from the original video. After a video clip is cut, the video clip will show on the right. When there are multiple video clips and the user wants to adjust the play order of those video clips, the user can drag any video clip and drop the video clip to a proper position as the user's wish. If the user thinks any video clip is redundant, the user can delete that video clip. After having video cut completed, the user can save the video clips sequence and create a final training experience narrative.

Annotation. Whenever there is an active canvas, the user can add annotations of different types like text, button, comment, flag, exclamation, star and so on, to that canvas. After annotations are added, the user can control any annotation the user wants. The user has to first select an active annotation by clicking any annotation the user wants to control. There are several buttons under the master-toolbar providing the user with the ability to control annotations. The user can change the text on annotations, move the position of annotations, rotate annotations, adjust the size of annotations, and delete annotations as the user wishes. After adjusting one annotation, the user can deselect the active annotation in case of misoperating the annotation or the user can select another annotation, letting the new annotation to become active and deactivating the previous one. An example of video annotations is demonstrated in Fig. 4.

Working Principle of The Editor. The editor works by manipulating virtual scenes that belong to multiple HTML5 canvases. For each canvas, there is a BJS Engine which handles the scene's rendering. BJS and the associated JavaScript allow us to create and manage the virtual scene, camera positioning, lighting, enabled controllers, etc. Primarily this is done by the use of a BJS Video Dome which is a convenient class allowing us to play and manipulate 360-videos. It does this by essentially projecting the video on an inverted sphere. So, we can conceptualize the editing framework as a collection of six spheres which are edited, viewed, manipulated independently of each other. Although it isn't obvious from the camera's perspective that you're inside a sphere, it becomes obvious if you scroll out.

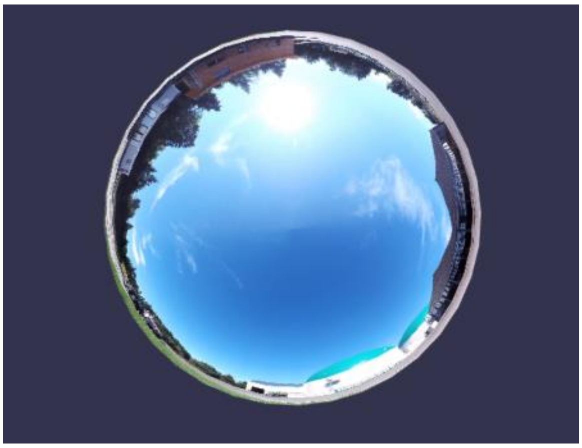

Fig. 5. Video Dome at a distance

4.3 Empeiría-V: The Viewer

As shown in Fig. 6, the VR-Viewer (*Empeiría-V*) has all the standard capabilities available in a modern web browsing experience. There is also a session interaction reporting component in the background which is the most important aspect of the viewer. The session interaction reporting reports data about user's headset orientation over time, gaze vector, etc. This session reporting is the primary data which drives the insights and analysis of the Extended Reality team and their education technology objectives.

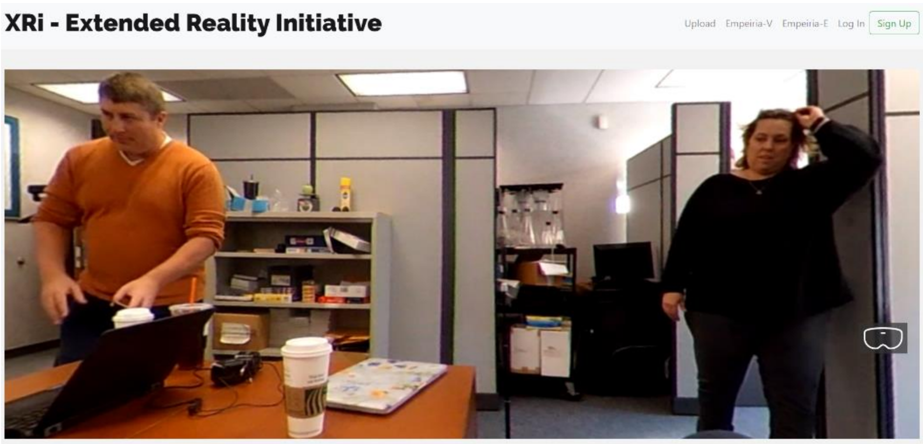

Fig. 6. Screenshot *Empeiría-V*

Fig. 7 portrays an immersive experience which is occurring on a conventional laptop, not an HMD. This is made possible because the framework is device agnostic and works with any compatible browser. Note that, it additionally works on an Oculus Go.

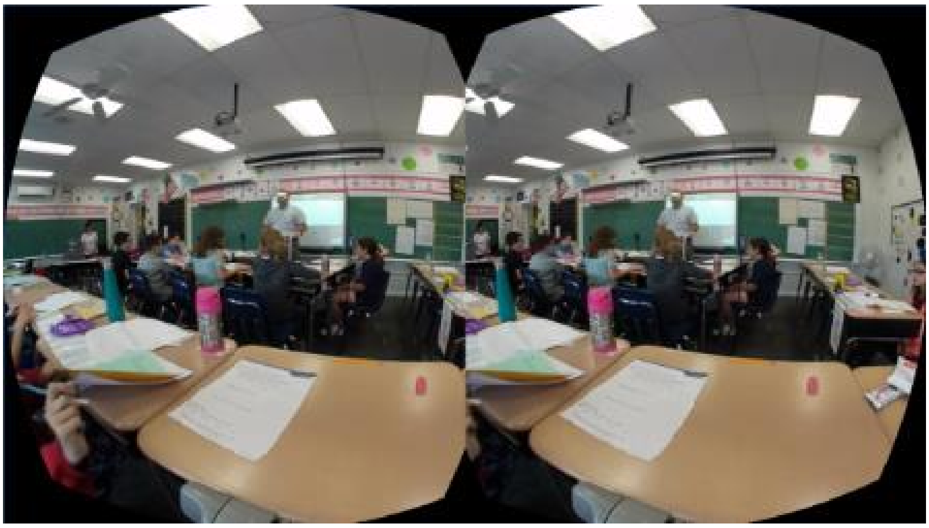

Fig. 7. Inside a VR Session

4.4 Data Model

We have designed the following data models in our framework. Fig. 8 presents entities in our data models and their relationships. "User" entity records information of each user. "Video" entity records information of each video. "Annotation" entity records information of each annotation. "VideoClip" entity records information of each sequence of video clips. "ViewerSession" entity records information of user's behavior when using the viewer. The relationship between two entities are represented by an arrow. All relationships between entities in our data models are one-to-many relationships, i.e. the entity pointed by the arrow has multiple entities that is on the other side of the arrow. One "User" entity has many "VideoClip" entities, "Video" entities, and "ViewerSession" entities. And one "Video" entity has many "Annotation" entities.

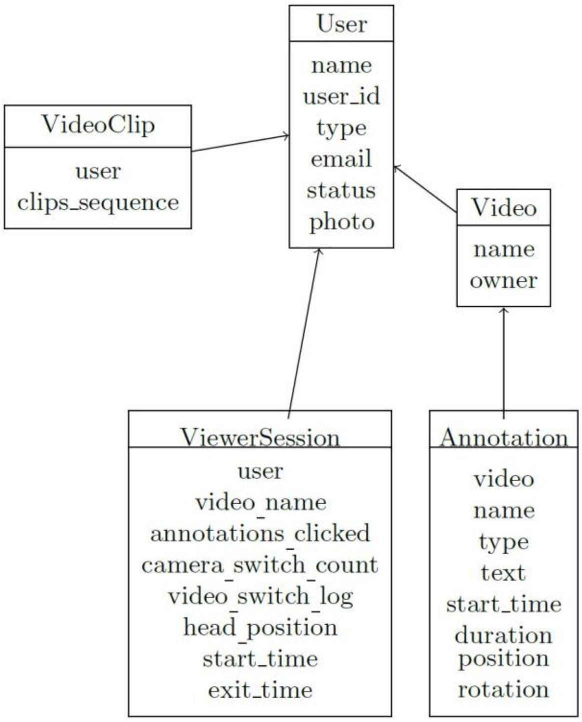

Fig. 8. Data Model and Relationships

5 Conclusion and Future Work

Immersive training experiences with high perceptual capacity 360-videos are improving professional development and training effectiveness. Trainees that are involved with immersive experiences can recall more details than their counterparts which experience standard videos. However, educators lack a convincing framework for creating immersive experiences, distributing them to trainees, and analyzing performance. *Empeiría* introduces that solution and helps extend the possibilities of professional development tools.

Furthermore, *Empeiría*, does so in a way that is open, highly accessible, device agnostic, platform independent, and novel. It takes advantage of cutting-edge technologies like Babylon.js, WebVR, and commodity HMDs. It offers a platform for mass-distributed WebVR, immersive experiences and attempts to overcome the software engineering challenges of working with developing specifications. The result is a powerful product and open framework for immersive training experiences, performance reporting, and simulation editing that requires only a browser. Ultimately, it provides a specialized and novel product for education technologists and enables developers to easily extend the framework with conventional web technologies.

This paper presented an introduction and overview of the open *Empeiría* framework, it proposed an existing education technology problem and provided a novel application of computer science to solve it. It explored the established literature on HCI, virtual reality, WebVR, and building immersive experiences for the web. Finally, it demonstrated concrete examples of the framework's components and its underlying architecture.

Future work will focus on developing and extending upon this early prototype of *Empeiría*. As part of this development, we will investigate video streaming and network optimization techniques, novel data visualization techniques, and other promising product improvements. Eventually, eye tracking functionality will be added to augment commodity HMDs and improve post-hoc trainee analysis. Beyond that, new techniques in artificial intelligence, machine learning, and computer vision are being investigated to extend our analysis capabilities and make judgements about the content of immersive experiences, student and trainee behavior, and performance trends.

Project progress can be found at https://xr.kent.edu/.

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