

# A Novel Tabletop and Tablet-Based Display System to Support Learner-Centric Ophthalmic Anatomy Education

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**Abstract.** This work couples the use of augmented and virtual reality, a tabletop display, and mobile devices (tablets and smartphones) to develop an innovative, system to support learner-centric anatomy education and training. The system provides a common tabletop interaction surface where a global view of an anatomical model is provided. This global view is available to all of the users (instructor and trainees) whom can interact with the model using the touch-sensitive tabletop display surface. In addition to this global view, each of the trainees has access to the model through a mobile device that is synchronized with the global view and provides each trainee with an individualized (local) view of the scene and interaction mechanisms. This paper outlines our integrated tabletop computer-tablet display and its use to facilitate virtual-based eye anatomy training.

**Keywords:** Tabletop computer, mobile device, anatomy education, individualized education, virtual reality, augmented reality.

## 1 Introduction

Human anatomy is an integral component of medical education that helps prepare the medical undergraduate trainee for their training in clinical specialties [3]. Human anatomy training also provides trainees with a first “impression” regarding the structure which forms the basis for understanding both pathologic and clinical problems [11], and is vital to ensure safe and efficient medical practice [12]. Human anatomy training often occurs in the laboratory with the instructor and the trainees around a cadaver table with a cadaver (or dummy

cadaver/manakin) placed on top of it. Such a scenario lends itself nicely to a tabletop display platform whereby the cadaver table and the cadaver are replaced with a tabletop display and three-dimensional rendering of the cadaver respectively. This allows the instructor and the trainees to interact actively with the rendered model (e.g., remove anatomical layers), as a group, similar to the traditional setting. Such an approach eliminates the use of a cadaver (at least during the early stages of anatomy training), and the complications associated with real cadavers (e.g., storage, acquisition and disposal, potential risk for pathogen transfer, and cost). Furthermore, it allows for numerous learning opportunities not available when working with a cadaver. For example, labels can overlay the anatomical structures to provide the trainees with information regarding the name and function of the structures. Although useful, the tabletop display and the supported interactions follow a “one size fits all” approach that does not facilitate learner-centric education whereby the instruction is tailored to each individual trainee to account for their prior knowledge level, background, and learning styles. How can one exploit the advantages of a shared tabletop display experience while providing personalized information and interaction to individual participants?

Taking advantage of the inherent collaborative nature of tabletop displays, we have recently begun developing a novel display system that couples a tabletop display, and mobile display technologies (e.g., tablets and smartphones) provided to each trainee, to overcome the “one size fits all” approach inherent when using a tabletop display on its own. Our display system provides a physical infrastructure for promoting learner-centered medical education whereby the information presented to each trainee’s mobile device is customized for them to specifically account for their level of learning (e.g., beginner, intermediate, advanced). Rather than multiplexing the main tabletop display as described by Smith and Piekarski [13], our novel infrastructure allows for the seamless interaction between the tabletop display and individual mobile devices.

Each trainee makes use of a mobile display and interaction device (e.g., a tablet or a smartphone) that is synchronized and localized within the global tabletop display, thus providing them with an individualized (local) and interactive view of the scene. This allows the trainees to share a common public workspace (i.e., the tabletop display), while having access to their own private workspace (i.e., mobile device). For example, a novice trainee may choose to view a labeling layer to augment the global view by providing labels to key components of the anatomical model being displayed, while a more advanced trainee may choose to view further anatomical information that includes more specific features than those presented in the global view intended for all of the trainees. Furthermore, the coupling of the tabletop display with the mobile devices enables those trainees who cannot interact with the global view directly (e.g., in a larger classroom setting where it is not feasible for each trainee to be placed around the tabletop display), to take advantage of what the others are doing through remote viewing on their mobile device. More specifically, trainees standing close to the tabletop display can obtain a first-person “hands-on” experience while

others lacking a direct line of sight may use their mobile device to keep track of what is happening thus allowing them to follow what others are doing on the tabletop display. This essentially extends the collaborative nature of the tabletop display to everyone in the room and beyond (e.g., those participating remotely), and not only to the limited number of trainees around it.

Although the infrastructure developed has a general purpose application structure, currently we are focusing on its application in eye anatomy education for medical trainees and technicians since the discrete anatomy of the eye's intricate oculomotor system is conceptually difficult for many novice trainees to grasp. Such training is difficult but clinically important given that the eye's oculomotor system is one of the most common sites of clinical intervention in the treatment of a variety of eye disorders [1]. For example, with respect to the ocular ultrasound procedure (a procedure that uses high-frequency sound waves to produce and measure detailed images of the eye), it is important to know where the resultant ultrasound beam is being placed according to the probe position and the eye structures being examined. The most challenging aspect of the ocular ultrasound procedure is the conversion of the two-dimensional slice of an image displayed on a conventional two-dimensional display into three-dimensional interpretations [8]. Despite the presence of simulators that allow for three-dimensional viewing, the majority of existing ophthalmic simulators demonstrate the equipment setup and three-dimensional image perception within a two-dimensional viewing environment but do not simulate the three-dimensional nature of the eye and its structure. This leads to problems for the trainee with respect to depth perception and spatial awareness, both of which are crucial given that the manipulation of instruments within the eye involves distances that are microscopic [8]. Virtual reality-based technologies can be used to facilitate the three-dimensional interpretation of two-dimensional image slices (e.g., using changes in perspective to allow the trainee to view different slices or a combination of slices), in a cost-effective and safe manner. Finally, it has been suggested that future ophthalmic surgeons can develop their hand-eye coordination and become accustomed to the small dimensions of the eye using virtual reality-based tools and technologies [16].

## 2 Background

Although use of tabletop displays in medical education is limited at present, there are several applications of tabletop displays intended to facilitate medical education and training. For example, the Anatomage Table resembles a typical operating table or hospital bed and the content obtained from real patients (e.g., data are from real patient scans or cadavers), perfectly illustrate the anatomical realism of a living human. The table is capable of displaying "true human gross anatomy in real life size" [2, 4]. Another example is the ongoing work of Dubrowski et al. [5] that is seeing the development of a strategy-based, learner-centric virtual learning environment (VLE) to facilitate interprofessional education in pediatric critical care. The system employs a tabletop display in

conjunction with novel image-based sensing and positioning technologies to enable multiple trainees (each taking on the role of one of the critical care team members), to work together in order to stabilize a pediatric patient.

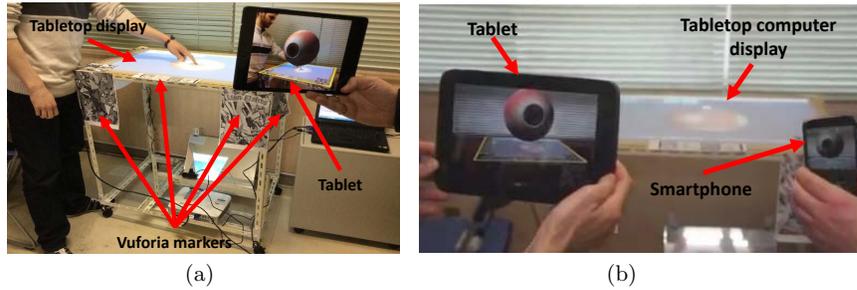
Specific to ophthalmology, we are not aware of any training applications that employ tabletop displays although several virtual simulations and computer-based training systems are currently available. For example, Allen et al. [1] developed an interactive, three-dimensional (3D) virtual model of the muscles and cranial nerves of the oculomotor system within the eye for eye-based anatomy education. The EON EyeSim Virtual Reality ophthalmic training simulator includes realistic three-dimensional ocular anatomy with interactive features, and allows trainees to explore the intricate structures of the eye including pupillary, ocular motility, and cranial nerve dysfunctions in a virtual patient [6].

### 3 Ophthalmoscope Training

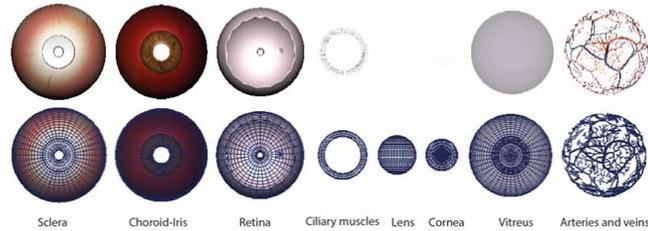
The test environment described here is intended to simulate and facilitate ophthalmoscope training (an ophthalmoscope is a diagnostic clinical device that allows for observing the eye on the inside from the retina). Initial stages of ophthalmoscope training involve reviewing the structures of the eye followed by training in the use of the ophthalmoscope itself. In this test application we utilize the tabletop-mobile device display in two different modes. In the first mode, (*anatomical mode*), the trainees learn the necessary anatomical aspects of the eye while in the second mode (*inspection mode*), the trainees learn to use the ophthalmoscope. In the inspection mode, the mobile device takes on the role of the ophthalmoscope and simulates the ophthalmoscope’s function (see [7]).

#### 3.1 Infrastructure

An overview of the integrated display/interaction system is provided in Fig. 1. There has been substantive work in the research and industrial communities on the integration of multiple hand-held devices with a common shared display, and this earlier work is leveraged here. For example, Nacenta et al. [9] examined the application of perspective to address issues associated with multi-display environments where the displays are at different locations and orientations to the trainee and developed a perspective-aware environment (E-conic) that supports dynamic perspective correction of graphical user interface (GUI) objects [9]. In the work presented here the displays and interaction surfaces of the mobile devices are rendered using the Unity game engine [10], and individual mobile devices are integrated through a common communication and 3D model infrastructure. A standard AR/VR marker-based localization system (described in Section 3.3) is employed to place the tabletop display and mobile devices within a common rendering 3D space and a communications infrastructure is used to ensure a common rendering model/interaction across all of the display devices. Models, anatomy databases, tracker marker data and the code-base itself are pre-deployed to all devices so that intra-device communication is limited to common state information.



**Fig. 1.** System overview. The tabletop display (anatomical mode) and individualized views as seen from the trainee’s viewpoint and displayed on their mobile device (inspection mode). (a) Vuforia markers placed around the tabletop display and single mobile (tablet) device. (b) Multiple mobile devices (tablet and smartphone).



**Fig. 2.** Decomposed 3D eye model with textures and edge views.

### 3.2 3D Eye Model

To obtain a suitable digital eye model, anatomical references were considered from traditional sources of study such as photographs, illustrations, and computer tomography scans by researchers and medical experts at the Mil. Nueva Granada University in Bogota, Colombia. This information allowed us to define the forms, the relations, and the textures of each of the eye’s parts. The 3D eye model is comprised of several layers and consists of 447,584 vertices and spherical mapped textures to provide realism (see Fig. 2). To allow content exploration, the model is comprised of several layers, each layer describing different anatomical structures of the eye. The anatomical model is rendered on the tabletop display and on each of the individual mobile devices running clients of the application. Trainees are able to augment the anatomical model on their devices as needed (e.g., a novice trainee can choose to label components of the anatomical model), while remaining grounded in the common view of the shared tabletop display. There are no explicit requirements on the model being used so any model can be substituted as necessary.

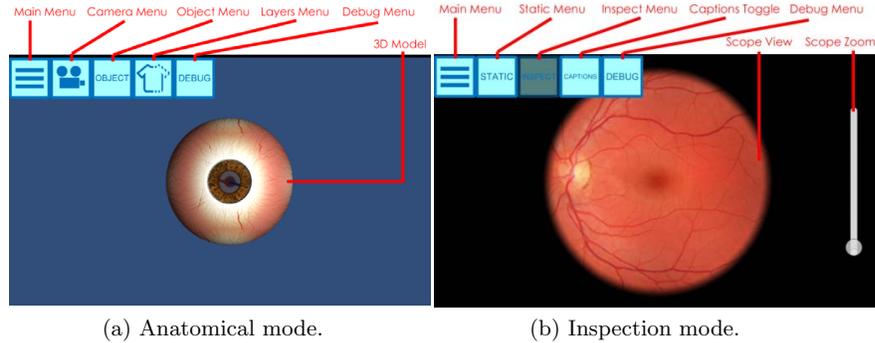
### 3.3 Tracking

Tracking the position and orientation of the mobile devices is accomplished using the Vuforia augmented reality platform [15]. The Vuforia platform is a marker- and computer vision-based tracking system that requires users to register visual markers within the working space of the application. Unique visual markers were printed and placed on top of and around the tabletop display (see Fig. 1(a)). By locating (and tracking) these markers, the position and orientation of the camera (on each mobile device) relative to these physical markers can be determined at interactive rates. Surrounding the tabletop display with visual markers allows for the mobile devices to synchronize (and communicate) with the tabletop display irrespective of their position. For proper operation, at least one of the markers must be visible to a mobile device.

### 3.4 The User Interface

As previously described, the tabletop display user interface is comprised of two modes: i) *anatomical mode*, and ii) *inspection mode*. The anatomical mode (see Fig. 3(a)), provides the trainees with an anatomical view of the eye and mechanisms to choose which aspects to display and whether they should be labelled in specific views. An orthographic view of the eye is rendered on the tabletop display (and to each individual mobile device), which trainees can manipulate (e.g., separate the components of the eye, toggle the visibility of the eye’s components, and zoom in/out). The anatomical mode interface consists of a main menu, camera menu, object menu, layers menu, and debug menu toggle. The main menu is used to switch to the inspection mode and to reset the program, whereas the camera menu is used to manipulate the camera in 3D space around the model (pan, zoom, rotate, and center). The object menu is used to select specific components of the model in 3D space in order to highlight them (with a red glow around the object), and present a menu with additional detail on the selected component. The layers menu is used to toggle the visibility of separate components of the model and the debug menu toggle is used to show additional information about the program such as frames per second (FPS) and the number of connected devices. The individualized view on each mobile device provides the trainee with a properly rendered 3D view of the anatomical model from the viewpoint of the individual trainee, allowing them to inspect the portions of the eye individually while being guided by the instructor.

In the inspection mode (available only on the mobile devices), the mobile device simulates the ophthalmoscope and provides the trainees with a “scope view” of the back of the cornea simulating the view that would be obtained with an actual ophthalmoscope (see Fig. 3(b)). In this mode, the trainee can zoom as desired and scroll the view of the back of the eye to highlight specific areas. Within this view, annotations can also be turned on in order to label different structural components of the cornea. The inspection mode allows the user to zoom the scope as well as pan the view of the cornea, whereby the anatomical structures of the cornea can be highlighted. The inspection mode interface consists of a main menu, static menu, inspect menu, captions toggle,



**Fig. 3.** Two modes of operation to support ophthalmoscope training. (a) The anatomical mode allows the trainees to learn about the necessary anatomical aspects of the eye. (b) In the inspection mode, the trainees learn to use the ophthalmoscope.

and debug menu toggle. The main menu is used to switch to the anatomical mode and to reset the program, while the static menu is used to set the tabletop display into a “static” state where it will not affect the scoped view. The inspection mode menu allows the user to zoom the ophthalmoscope and pan the view of the cornea, while the captions toggle toggles the visibility of highlights showing the separate components of the cornea. Finally, the debug menu toggle is used to show additional information about the program including frames per second (FPS), and the number of connected devices.

The tabletop display and paired mobile devices interact on a tabletop-dependent basis. In other words, the position and rotation of the model in addition to the visible status of each individual component comprising the model are controlled at the tabletop display. Rotating the model on the tabletop display correspondingly rotates the world-space orientation of the eyeball on each mobile device’s view. Similarly, hiding separate components of the model on the tabletop display also hides these components in the mobile device view.

### 3.5 Communication Architecture

An overview of the communication architecture is provided in Fig. 4. Each mobile device establishes a connection with the tabletop display and once this connection has been established, two-way communication between the mobile device and the tabletop display can take place. Communication is facilitated through the exchange of native C# objects in the form of Javascript Object Notation (JSON) strings [14]. Each JSON string contains sufficient information to reconstruct the object at the receiving end of the communication pipeline. This enables a common global state to be maintained across all of the rendering devices (tabletop display and mobile devices), and for interactions on the individual devices to be reflected in the display available on each.

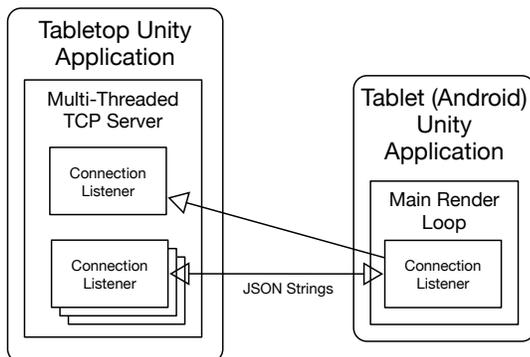


Fig. 4. Communication architecture overview.

#### 4 Discussion and Future Work

Virtual simulation can provide a safe and cost-effective alternative to traditional medical education and training methods. However, virtual simulation rarely facilitate a learner-centric approach whereby the information presented to the trainees is customized/individualized to each trainee on a per-needed basis. Here we have described preliminary work towards the development of a novel display system that couples a tabletop display with mobile devices (e.g., one or more tablets or smartphones), that are allocated to each trainee, to promote learner-centered human anatomy education. Although coupling multiple devices is not necessarily novel, our contribution includes the novel infrastructure that allows the seamless interaction between the tabletop display and the individual mobile device to promote learner-centric simulation-based education.

An often identified advantage of a tabletop display is its ability to promote collaboration amongst its users (trainees) and therefore, it is a concern that providing each trainee with a mobile device that they interact with during the training session may interfere with the inherent collaborative nature of the tabletop computing platform. However, the benefits this interface provides, outweighs this potential drawback. The user interface is designed to provide flexibility to its users and to ultimately facilitate learner-centric simulation-based education. The mobile device is intended to augment the primary tabletop display and provide individualized information to the trainees as needed. Furthermore, it also allows the number of trainees to take part in a particular training session to be increased beyond the few that are located around the table and able to physically interact with it. Trainees can now participate in the training session remotely and can, through their mobile device, not only view the training session, but become active participants within it. Finally, the system can operate with the tabletop display alone with zero or more mobile devices and thus the instruc-

tor/educator ultimately has the freedom to choose how the training session is to proceed.

Although we have developed a functioning prototype, further work remains. More specifically, currently trainees are able to view their mobile devices as they wish. Future work will further investigate the interaction between the main tabletop display and the mobile devices and this will include examining various models of interaction between the tabletop display and the mobile devices. For example, rather than allowing each trainee to interact with their mobile device as they wish, perhaps the instructor should control when to activate a particular mobile device and determine what information to provide the mobile device with. Future work will also examine what, if any, effect the individual mobile devices (with their associated different view and augmented information), have on the collaborative nature of the tabletop display.

Informally, the Vuforia marker-based tracking platform that is used to synchronize the individual mobile devices with the tabletop display has demonstrated decent performance. However, relying on specific preregistered visual-based markers is prone to tracking errors depending on the ability of the mobile device to locate the target. Although we have surrounded the tabletop display with a large number of visual targets, there is a possibility that all visual targets will be occluded to one or more mobile devices, particularly when considering a large number of trainees positioned around the tabletop display. This is further complicated as the distance between the mobile device and the tabletop display is increased. In addition, localization and tracking of the target can be greatly influenced by various external factors including lighting conditions, and occlusion of the targets by objects and other users in the environment. Future work includes improving upon the Vuforia-based tracking method and conducting usability testing of the system to examine the functionality of the user interface, and user-based interactions. Finally, future work will also see more thorough pre- and post-testing of the eye simulation with medical students (including ophthalmology trainees), to quantify its effectiveness as a learning tool.

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