Optics education in an optometric setting

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ABSTRACT

The first year optics curriculum at the Arizona College of Optometry aims to provide students with an understanding of geometrical, physical, and visual optics principals that will be the foundation of their clinical understanding of the optics of the eye and its correction in advanced courses such as ophthalmic optics and contact lenses. Although the optics of the eye are a fantastic model to use in optics education, the clinical applications may not become apparent until later in the course of study. Successful strategies are needed to engage students and facilitate the understanding of optical principals and the growth of process skills including problem solving, analysis, and critical thinking that will help in their future as health care providers. These include the implementation of ophthalmic applications as early as possible, encouragement of group work including open office hours, and the use of video problem set solutions to supplement traditional static solutions.

Keywords: Geometrical optics, biomedical optics, optometry, education, ophthalmic optics, eye, vision, ametropia

1. INTRODUCTION

The Arizona College of Optometry (AZCOPT) on Midwestern University's Glendale, AZ campus provides students with a four-year didactic and clinical education, awarding the degree Doctor of Optometry (OD) upon successful completion of the professional curriculum. The first year optics curriculum aims to provide students with a well-rounded understanding of geometrical, physical, and visual optics principals that will be the foundation of their clinical understanding of the optics of the eye and its correction in advanced courses. The optometry student population at AZCOPT largely comes from a background in the biological sciences with limited prerequisite requirements in math (3 semester hours), statistics (3 semester hours), and physics (6 semester hours) and enrollment in the program requires successful completion of a baccalaureate degree from a regionally accredited institution. As a result, introductory optics courses start with an assumption that student backgrounds with vary broadly and include a two-quarter geometrical and physical optics sequence followed by a one quarter visual optics course. These are followed in later years by advanced courses requiring knowledge of the optical principals from the first year curriculum including optometric methods, ophthalmic optics, contact lenses, and low vision[1-3].

The optics of the eye are a fantastic model to use in optics education as the visual experiences of looking at distant and close objects and using correcting devices such as glasses and contact lenses are a part of students' everyday lives. This is true in particular for students in an optometric program where the subject of study revolves around the eye. The optical system of the eye may be easily simplified to a one surface model or expanded to a more complex model. The consideration of refractive states and their correction may also be simplified or extended to include more advanced considerations such as physical optics limitations to vision, depth of field, and ocular aberrations. That said, the clinical applications may not become apparent until later in the course of study[4-10].

In a professional optometric program, successful teaching strategies are important to engage students and facilitate the fundamental understanding of optical principals as well as the growth of process skills including problem solving, analysis, and critical thinking that will help in their future as health care providers. These include the implementation of ophthalmic applications as early as possible, encouragement of group work including open office hours, and the use of video problem set solutions to supplement traditional static solutions. These have been particularly successful in helping students develop skills that require dynamic processes such as properly identifying the question that is being asked, applying technical knowledge in order to determine a solution, and questioning the validity and/or meaning of a solution.

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2. GEOMETRICAL, PHYSICAL, AND VISUAL OPTICS CURRICULUM AT THE ARIZONA COLLEGE OF OPTOMETRY

The geometrical, physical, and visual optics curriculum at the Arizona College of Optometry can be broken up into three general categories with those respective names. There is considerable overlap, in particular with the visual optics components as the definition can be broad and many of the geometrical and physical optics concepts are taught in order to establish an understanding of the optical system of the eye and its correction.

There are three optics courses in the first year curriculum at AZCOPT: Geometrical and Physical Optics I & II, each 4 credit hours with a laboratory component, and Visual Optics, which is a 2 credit hour course with a workshop component. Ten hours of lecture time, twenty hours of workshop time, or thirty hours of lab time constitute 1 credit hour. These courses serve to introduce the optical principals important for understanding the optics of the eye and its correction. One goal is to establish a strong geometrical basis of the refraction of light early in the program with optometric applications to form a basis for understanding more advanced concepts later in the program. The students are directed to two primary resources throughout the first year curriculum: Geometric, Physical and Visual Optics by Michal P. Keating and Geometrical and Visual Optics: A Clinical Introduction by Steven H. Schwartz[11,12]. These are both specialized optometric optics books. Schwartz's book was recently updated in 2013 and is extremely easy to read, providing a great introduction, summary, and/or review of optometric optics concepts. Keating's book offers an increased level of detail and depth for a variety of topics with many mathematical examples throughout the text and a variety of practice problems. Additional resources are also used in these courses, in particular for the visual optics applications[13-15]. Table 1 outlines some of introductory geometrical optics content in the first course in the AZCOPT curriculum.

Table 1. Selected geometrical optics concepts taught at the Arizona College of Optometry.

SELECTED GEOMETRICAL OPTICS CONCEPTS	
<u>Introduction</u> • Waves, wavefronts, and rays • Converging, diverging, and parallel light • Pinhole imaging • Real and virtual objects and images <u>Single Spherical Refracting Interfaces</u> • Radius of curvature, refractive indices, focal points, nodal point, dioptric power • Convex / Concave, Converging / Diverging, Positive / Negative interfaces • Refraction at a spherical surface, object-image relations and lateral magnification <u>Thin Lenses</u> • Ray diagrams and paraxial imaging equations • Problem solving with multiple thin lenses <u>Spherical Ametropia and Thin Lens Eye Models</u> • Emmetropic, myopic, and hyperopic eyes • Far point, near point, accommodation, and ranges of clear vision • Refractive correction at spectacle and corneal planes • Changes in retinal image size with different forms of spherical ametropia (axial vs. refractive)	<u>Cylindrical Lenses and Astigmatism On Axis</u> • Power vs. axis for cylindrical and sphero-cylindrical lenses • Locating line foci • Circle of least confusion • Sturm's conoid • Imaging vs. correction of astigmatic eye models <u>Thick Lenses</u> • Focal points, nodal points, and principal planes (cardinal points) for thick lenses and systems • Vergence equations for thick lenses and systems • Back vertex power and neutralizing power <u>Prisms</u> • Prism deviation and prism diopters with ophthalmic prisms • Thick prisms and total internal reflection <u>Reflection and Mirrors</u> • Law of reflection • Imaging with flat and curved mirrors

A few weeks in the beginning of the first quarter are spent establishing definitions and sign conventions, but visual and optometric applications are introduced from the first day. Once some basic principles are established, units on ametropia and astigmatism are introduced in order to keep the clinical applications front and center as early as possible. In addition, labs are held in two groups every week and students get a hands-on experience with different optical models, helping them understand the concepts taught in the class (see below for more details).

Physical optics concepts are important in optometric applications including polarization, anti-reflective coatings, scattering, and the diffraction limits to vision. Table 2 outlines some of physical optics content in AZCOPT curriculum.

Table 2. Selected physical optics concepts taught at the Arizona College of Optometry.

SELECTED PHYSICAL OPTICS CONCEPTS	
<u>Waves and Superposition</u> • Basic wave properties, harmonic waves, intensity, superposition, interference, and standing waves • Double-slit interference, speckles, and laser refraction • Thin film interference, phase changes upon reflection, soap films, and anti-reflective coatings	<u>Diffraction</u> • Diffraction from single slits, square, rectangular, and circular apertures • Resolution and the Rayleigh criterion <u>Polarization and Scattering</u> • Polarizing films, transmission of light through polarizers • Polarization by reflection • Incoherent scattering and Rayleigh scattering

Visual optics brings many of the geometrical and physical optics concepts together in ophthalmic applications. Table 3 outlines some of visual optics content in AZCOPT curriculum.

Table 3. Selected visual optics concepts taught at the Arizona College of Optometry.

SELECTED VISUAL OPTICS CONCEPTS	
<u>Angular Magnification</u> • Simple magnifiers, microscopes, and telescopes • Spectacle magnification <u>System Stops and Pupils</u> • Aperture stops and field stops • Fields of view <u>Ocular Image Quality and Aberrations</u> • Monochromatic aberrations • Chromatic aberrations • Zernike classifications • Spatial frequency, the Modulation Transfer Function and Contrast Sensitivity	<u>Schematic Eye Models</u> • Thin lens eye models through multi-surface models and their uses • Purkinje images <u>Optics of Ophthalmic Instruments</u> • Slit lamp biomicroscope • Keratometer • Goldman tonometer • Gonioscopy lenses • Retinoscope • Direct ophthalmoscope • Binocular indirect ophthalmoscope (BIO) • Lensometer • Optical Coherence Tomography (OCT)

3. LABORATORY AND WORKSHOP DEMONSTRATIONS

An important learning tool in the first year optics sequence at AZCOPT is laboratory and workshop demonstrations. The Geometrical and Physical Optics I & II course sequence includes a weekly 3 hour lab component where a variety of laboratory activities and problem solving sessions have been developed to facilitate student learning.

3.1 Laser Ray Boxes

One very useful tool used to aid visualization of geometrical optics concepts in laboratories and workshops at the Arizona College of Optometry are laser ray boxes and sets of optics specifically designed for use with the laser ray boxes. The equipment currently being used at AZCOPT was purchased from Arbor Scientific (http://www.arborsci.com/laser-ray-box-and-lenses). The laser ray boxes allow students to isolate one, three, or five parallel beams that can be sent through the accompanying optics including converging and diverging lenses, parallel zero powered optics, and prisms.

There are many activities and demonstrations possible with the laser ray boxes and accompanying optics. The refraction of light through different optical elements is visualized through observations of the individual laser beams. The idea that individual converging and diverging lenses have different shapes that result in the light converging or diverging is clearly demonstrated with these systems. In addition, systems of lenses such as the one shown in figure 1, may be used to demonstrate image formation and the ideas of real and virtual objects and images. Systems of lenses may be used to demonstrate the idea that the image from one lens becomes the object for a second lens (and so on). This is true even if that first image is never allowed to form, thus creating a virtual object. Other concepts including prism deviation and spherical aberration are also able to be demonstrated with these setups[16].

Figure 1 shows a system of three converging and diverging lenses in a system that students could use to understand real and virtual objects and images, converging and diverging light.

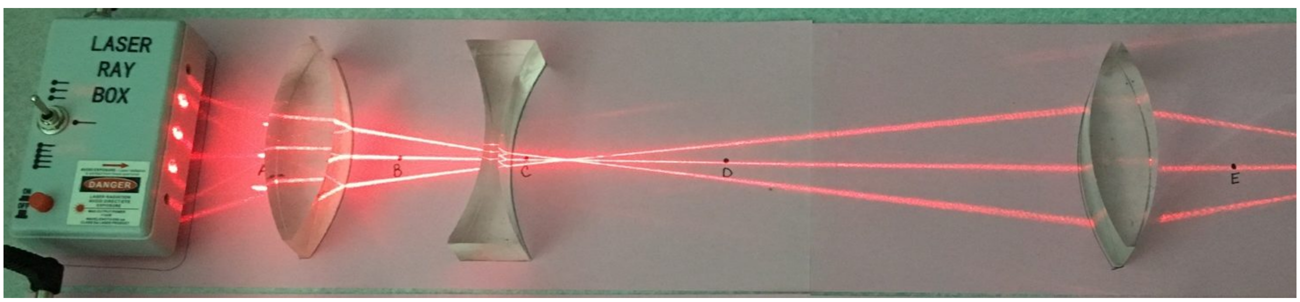

Figure 1. Laser ray box with converging and diverging lenses. Here points A, B, C, D, and E represent points where students could identify parallel, converging, or diverging rays and wavefronts, positive, negative, or zero vergence, and real, virtual or distant objects and images for each lens.

3.2 Introductory Model Eye Demonstrations

Many of the labs are designed to introduce model eyes and concepts. An introductory lab includes laboratory demonstrations with a jumbo functioning eye model setup that includes an adjustable liquid lens from Denoyer-Geppert, which may be seen in figures 2 and 3 (https://denoyer.com/products/jumbo-functioning-eye). This model eye is useful in introductory discussions and includes many features that are useful in the demonstration of ophthalmic concepts including: an object eye chart, a holder for correcting lenses, an adjustable diaphragm that may be filled with water to change lens power, and an adjustable screen/retina with marks for the fovea and optic disk/blind spot. The adjustable eye chart allows demonstrations of the model eye looking at distant or close objects and the resulting need for a more powerful eye and either the use of an additional lens (bifocal) or the addition of power to the lens in the eye (accommodation). Although the eye model is not anatomically demonstrating the concept of accommodation, it is able to clearly demonstrate a dynamic change in power and resulting range of clear object distances. This eye model is also useful in the introductory discussion of emmetropic eyes and the concepts of myopic (nearsighted) and hyperopic (farsighted) eyes that are a result of a mismatch between the eye's power and its length. It also includes an opportunity to demonstrate the use of correcting lenses.

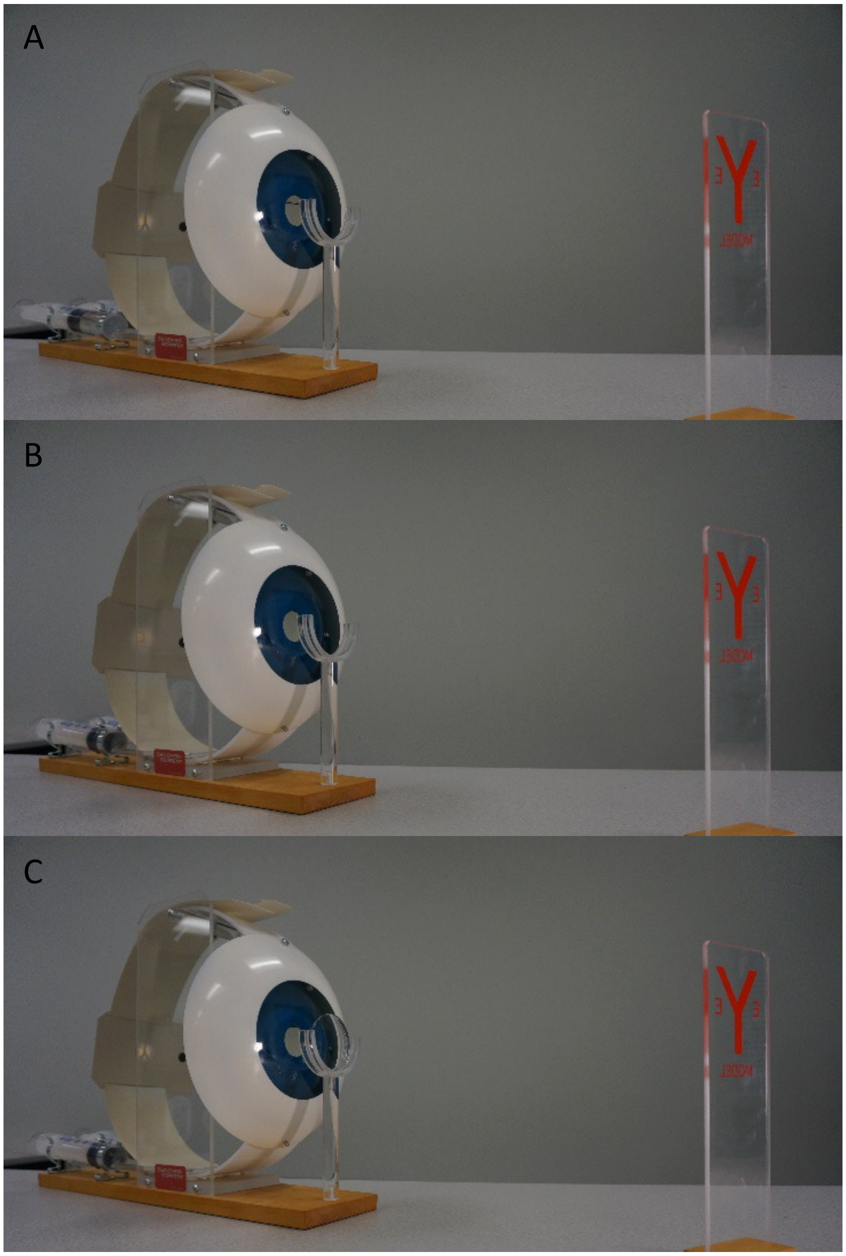

Figure 2. Model eye used in an introductory Geometrical and Physical Optics lab. The eye model includes many features that are useful in the demonstration of ophthalmic concepts including: an object eye chart, a holder for correcting lenses, an adjustable diaphragm that may be filled with water to change lens power (see figure 3), and an adjustable screen/retina with marks for the fovea and optic disk/blind spot. The top image shows the eye in focus, the middle figure shows a situation with more water added to the adjustable lens and as a result a more powerful eye that is out of focus. The bottom image shows the eye brought back into focus with an external lens.

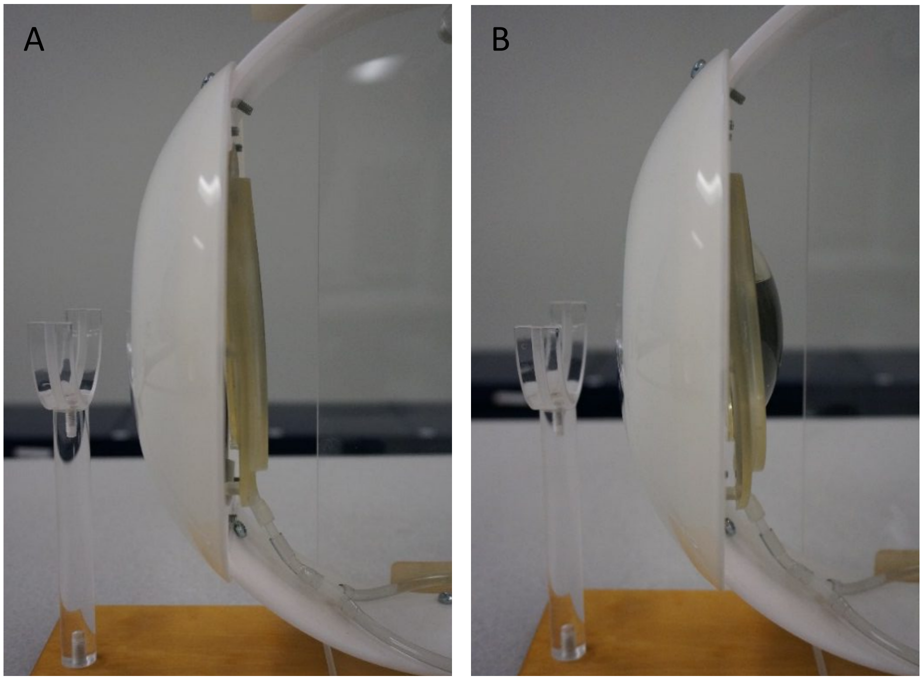

Figure 3. Close-up images of the adjustable lens from the model eye discussed in figure 2. The adjustable diaphragm is shown on the left with no water and on the right filled with water. The increase in radius of curvature and increase in power can be used to demonstrate ophthalmic concepts including myopic and hyperopic eyes and accommodation.

3.3 Model Eyes for Laboratory Demonstrations of Spherical and Sphero-cylindrical Ametropia

Another set of laboratory equipment used at the Arizona College of Optometry are optical rails and trial lens holders that the students use with their personal lens kits from Pioneer International (http://www.pioneerdoctor.com/). There are a variety of objects and lenses that can be used and one of the major applications is eye models. In various Geometrical and Physical Optics labs, students create emmetropic, myopic, hyperopic, and astigmatic eye models. Students work to understand far points, near points, accommodation, and ranges of clear vision. Students are also able to correct these eye models with lenses in contact with the eye models (contact lenses) and lenses in front of the eye models to simulate spectacle corrections. This can help with the understanding of the adjustment of lens powers and spectacle magnification factors. Figures 4-5 demonstrate some of the eye models used at AZCOPT.

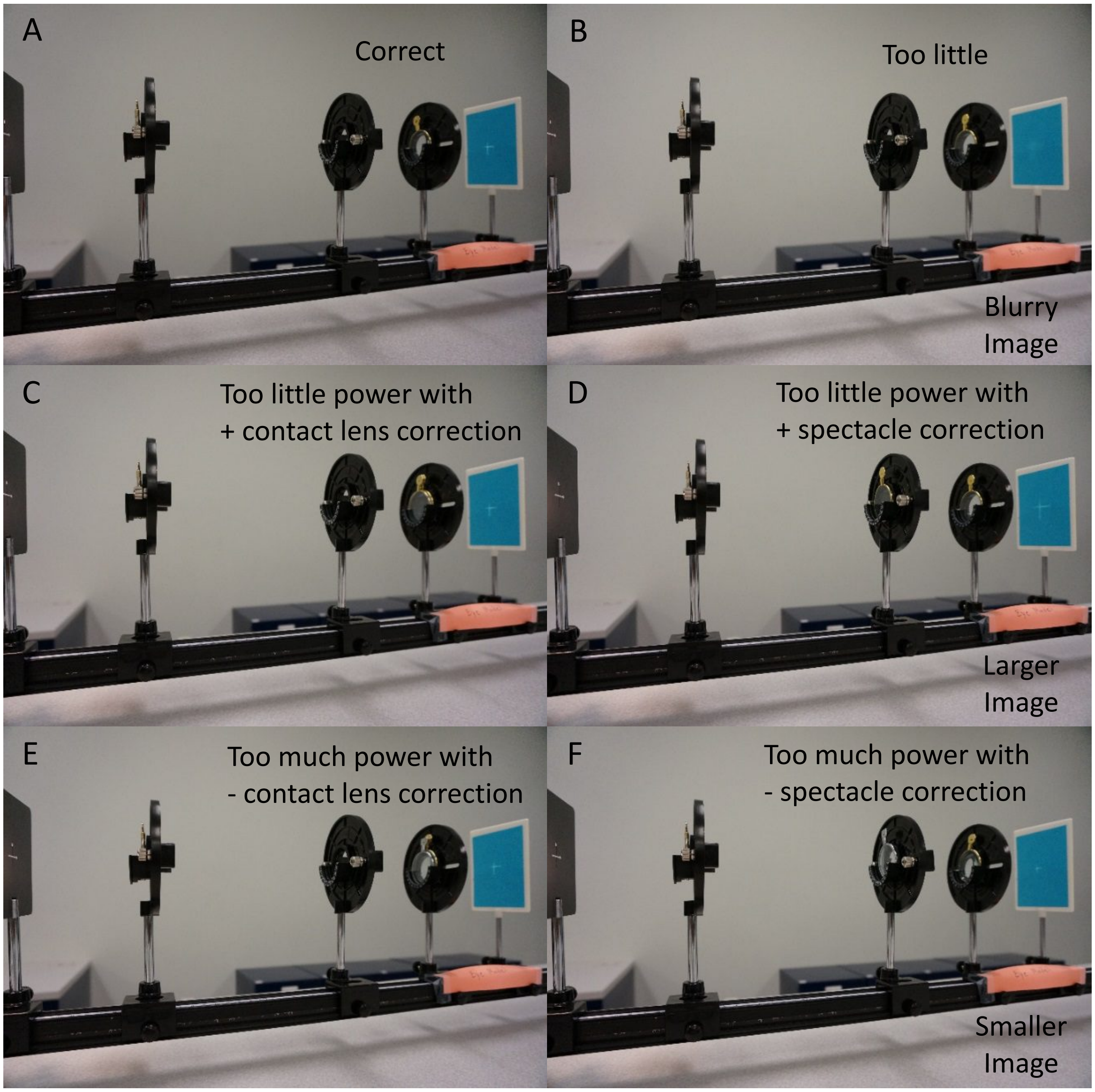

Figure 4. Examples of model eyes used in Geometrical and Physical Optics demonstrations of ametropia. Figure 4A shows an eye that is in focus for a distant object, an emmetropic model eye. Figure 4B shows an eye with less power that is out of focus for the screen/retina at the same distance, simulating a hyperopic eye. Figure 4C shows the hyperopic eye model brought back into focus with a positive correcting lens in contact with the eye lens demonstrating a contact lens correction. The resulting retinal image that is the same size as the emmetropic retinal image from figure 4A. Figure 4D shows the same hyperopic eye model brought back into focus with a weaker positive correcting lens compared with the one used in figure 4C that is held in front of the eye lens demonstrating a spectacle lens correction. The resulting retinal image that is larger than the emmetropic retinal image from figure 4A and the contact lens corrected hyperopic retinal image from figure 4C, demonstrating a spectacle magnification factor. Figure 4E shows a myopic eye model (an eye with more power that is out of focus for the screen/retina at the same distance) brought back into focus with a negative correcting lens in contact with the eye lens demonstrating a contact lens correction. The resulting retinal image that is the same size as the emmetropic retinal image from figure 4A. Figure 4F shows the same myopic eye model brought back into focus with a stronger negative correcting lens compared with the one used in figure 4E that is held in front of the eye lens demonstrating a spectacle lens correction. The resulting retinal image that is smaller than the emmetropic retinal image from figure 4A and the contact lens corrected retinal images from figures 4C and 4E, demonstrating a spectacle magnification factor.

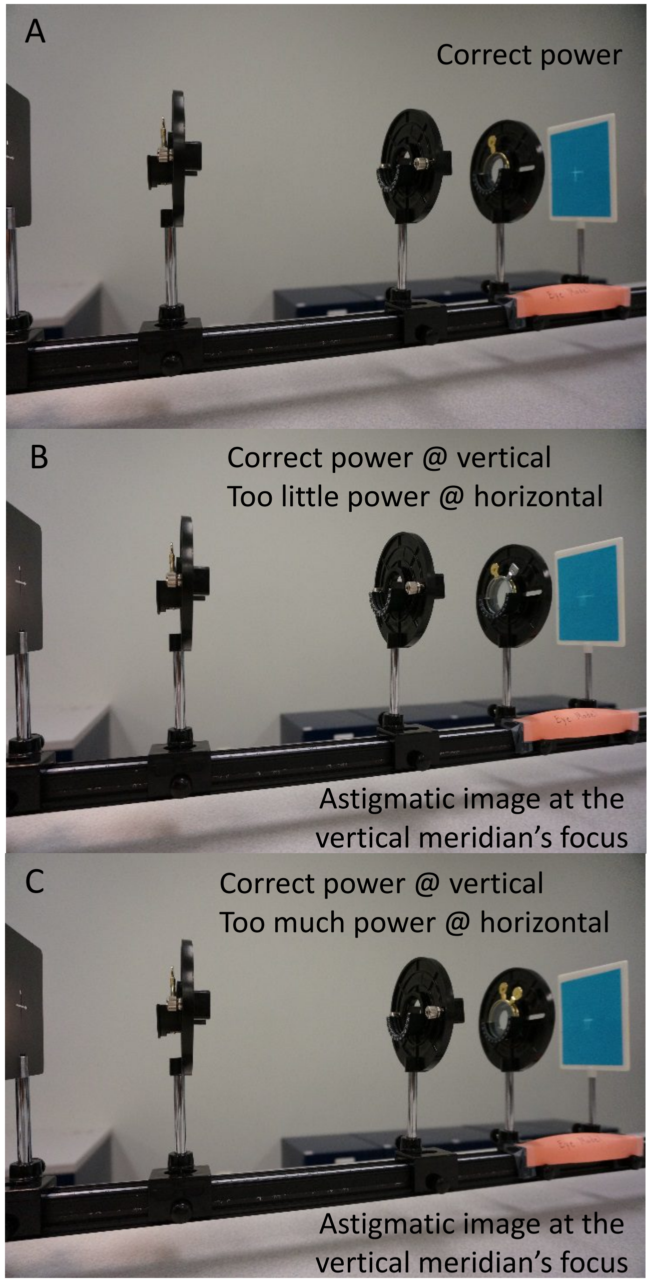

Figure 5. Examples of model eyes used in Geometrical and Physical Optics demonstrations of ametropia and astigmatism. Figure 4A shows an eye that is in focus for a distant object, an emmetropic model eye. Figure 5B shows the same eye with the addition of a negative cylindrical lens, creating a simple hyperopic eye model that is in focus for the vertical meridian. A second line focus may be found behind the retina. Figure 5C shows the same eye with the addition of a positive cylindrical lens, creating a simple myopic eye model that is in focus for the vertical meridian. A second line focus may be found in front of the retina. These eye models may be used to discuss the relationship between power and axis in cylindrical and spherocylindrical lenses. These eye models may also be used to demonstrate and discuss the relationship between the lenses that comprise the eye model and the lenses that may be used to correct that eye model.

4. PROBLEM SOLVING

Course materials are often mere snapshots that fast-forward the student from a question to an answer, ignoring the procedures and thought processes where mistakes are commonly made and a more complete understanding of the solution is formed. A preliminary teaching method using video solutions to supplement traditional problem solutions can be used to fill this gap in the optometric optics education setting.

In the Geometrical and Physical Optics I course at the Arizona College of Optometry at Midwestern University, video solutions were provided in addition to the traditional pdf solutions for approximately 70% of required problems on the problem sets that were assigned in addition to lectures and labs. A total of 34 video solutions averaging 7.0 minutes in length (range 2.3 minutes to 14.6 minutes) were uploaded through the Kaltura Media platform integrated into the Blackboard course page. Preliminary feedback was extremely positive and anecdotal evidence suggested that most students who utilized the video solutions perceived a benefit.

5. CONCLUSIONS

Introducing optometric applications as soon as possible as well as incorporating dynamic and interactive teaching methods is helpful in the teaching of geometrical, physical and visual optics concepts in a professional optometric curriculum. Extending the concepts learned in the classroom to the lab and vice-versa is extremely important and can facilitate this learning process.

6. ACKNOWLEDGEMENTS

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