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Optometric Education *The Journal of the Association of Schools and Colleges of Optometry*

An Inquiry-Based Approach to Teaching Sphero-Cylindrical Ametropia | 1

Abstract

Two inquiry-based laboratories on cylindrical and sphero-cylindrical lenses and sphero-cylindrical ametropia were implemented in the Geometrical and Physical Optics I course at the Midwestern University Arizona College of Optometry. Inquiry-based methods emulated the process by which scientists conduct research and optometrists analyze difficult cases, enhancing students' investigation and reasoning skills. A variety of supplies for approaching problems, including household vases, traditional optical rails and educational eye models, were provided. The traditional lab and the inquiry-based labs were compared, and subjective comments from students highlighted the advantages of the different approaches. Inquiry-based labs, in particular with practice and guidance, can enhance student understanding and provide a memorable and valuable learning experience.

Key Words: *optics, astigmatism, optometric education, geometric*

Background

A clear understanding of the optics of the eye remains a fundamental basis of optometric education.[1-7] As technology continues to improve, modern instrumentation and corrections can utilize measurements that are more sophisticated and manufacturing standards that are more precise. Optometrists need a clear understanding of the optical basis of sphero-cylindrical ametropia and the relationship between the refractive state of the eye and its correction to be able to evaluate and utilize new and evolving technologies.

Students in the first-year program at the Midwestern University Arizona College of Optometry (AZCOPT) are required to take the OPTOG 1540 Geometrical and Physical Optics I course as part of the OD-1 curriculum. The course is in the first quarter of the optometric program and includes 30 hours of lecture and 10 three-hour laboratory periods over the course of the 10-week quarter. Lecture and laboratory materials were developed over the course of five administrations with the same course director. The entire class (approximately 55 students) attends lecture together and two laboratory sections are scheduled on the same day with approximately half the class randomly assigned to each section at the beginning of the quarter. The laboratory is equipped with eight stations with optical rails, lights, optical elements and other supplies. Most labs contain traditional demonstrations and activities designed to give students hands-on experience with the lecture content. Labs are designed to take place after the introduction to material in lecture, and each laboratory has a pre-lab reading assignment. A pre-lab assignment and a post-lab assignment are graded.

At AZCOPT, students learn the fundamental concepts of spherical and sphero-cylindrical ametropia in their first quarter of study in the Geometrical and Physical Optics I course. For many years, sphero-cylindrical ametropia was taught through a series of approximately six hours of lecture and one three-hour laboratory. Sphero-cylindrical ametropia is one of the most clinically relevant topics covered in the first-year optics curriculum and one of the most challenging. Some of the related course learning goals are summarized in **Table 1**. The introduction first-year optometric students receive in this course forms the basis upon which they learn advanced concepts related to spherical and sphero-cylindrical ametropia in optometric methods, contact lens and low vision courses and ultimately translate to clinical knowledge.[8-9] Understanding cylindrical and sphero-cylindrical optics necessitates thinking about an optical system in three-dimensions, and students often comment that the relationship between the power of the eye/lenses and the orientation of images is difficult to visualize. Students also share that it is difficult to simultaneously consider the relationship between the power of the eye (keratometry), the power of a prescription (ophthalmic optics) and the various notations used to represent these components (transcription). Students often show a gap between the knowledge they should have obtained about sphero-cylindrical optical systems and what they display on examinations and in their methods courses.

TABLE 1
Learning Goals Related to Spherical and Sphero-Cylindrical Ametropia in OPTOG 1540 Geometrical and Physical Optics I

- To be able to explain the optical basis of refractive error, its measurement and its correction
- To understand thin lens models of ametropia
- To understand the changes in refractive power between the spectacle and corneal planes
- To understand changes in retinal image size with different forms of ametropia (axial vs. refractive)
- To understand thin lens spherical and sphero-cylindrical imaging with point objects and images as well as extended objects and images
- To understand the relationship between power and axis meridians
- To understand the difference between plus and minus cylinder notations and convert between the two
- To understand the difference between using a cylindrical lens to form an image and looking through a cylindrical lens (the role of the eye)
- To understand the interval of Sturm
- To understand the characterization of astigmatisms in the human eye

Table 1. Click to enlarge

TABLE 2
Comparison Between Inquiry-Based and Traditional Sphero-Cylindrical Ametropia Labs

Traditional Lab	Inquiry-Based Lab
Students follow step-by-step instructions to make observations	Students make observations at starter stations to gain exposure to a variety of phenomena
Students receive a hands-on experience with complex material	Students define and investigate an aspect of the material that is of interest to them
Students follow a clearly defined process to ensure exposure to all content goals	Students communicate their results with the class and become subject-matter experts

Table 2. Click to enlarge

There are many possible approaches to the design and execution of learning activities in the laboratory setting. There is a long history of laboratory use in science education, which is believed to provide students with valuable experiences with science concepts and the processes required in scientific fields. An inquiry-based laboratory is one way to increase the depth of conceptual and quantitative understanding and stimulate critical-thinking.[10-18] Here, inquiry refers to the fact that students learn process skills relevant to optometric practice, such as problem-solving, data analysis and communication, along with the content centered on the concepts of sphero-cylindrical ametropia. Traditional laboratories on the other hand can be any hands-on activity outside a lecture setting where students work to visualize information. They can provide a hands-on and active experience with the material, but in a traditional lab, learners are typically following a set, clearly defined procedure to simply observe and record findings. This could include activities with physical materials or computer simulations that often at least appear to have a “right” answer with errors attributed to malfunction or human error. The learning goals for traditional laboratories are typically content-driven rather than process-driven.[19-24] Traditional lectures and laboratories are widely accepted as effective methods to deliver basic content to students and have a long history of use in scientific education. A comparison between the two methods is presented in **Table 2**.

Inquiry-based teaching methods were used in an optometric setting by the author as a graduate student instructor in an ophthalmic aberrations laboratory. This lab was an additional lab in that course and allowed students to look at their own aberrations using a computer simulator. Then they worked in groups using a case-based approach to further investigate one condition or clinical problem. One major question remains. Are inquiry-based labs well-suited to replace traditional labs in an optometric setting, or are they better suited to be used to strengthen and widen the scope of knowledge? In addition, if used in combination with a traditional laboratory, is there an ideal order to present the labs: inquiry then traditional or traditional then inquiry?

Methods

Two innovative and interactive laboratories with an inquiry-based and a traditional component on sphero-cylindrical ametropia were implemented, replacing the one traditional lab on sphero-cylindrical lenses and the laboratory practical exam. To increase the depth of knowledge of the refracting states of the eye and their correction, inquiry-based sphero-cylindrical ametropia laboratories provide students with an opportunity to further explore and work with eye models and their own visual systems to increase the depth of their understanding of these concepts. This innovative laboratory approach can be challenging and lead to periods of questioning, but ultimately the goal is to extend the students’ fundamental understanding of a set of topics (e.g., Table 1) that form the basis of understanding in many future classes and future clinical practice.[16,18,20] Inquiry-based laboratory activities can be challenging to students as they are more open-ended with students taking ownership over the scientific process. They often hit a point where they are stuck or do not know how to proceed, as is the case in the practice of vision science and optometry. As a result, more instructors and teaching assistants facilitated the inquiry-based lab periods to help the students design and execute their investigations compared to a traditional lab setting. (Most sessions had three to four for inquiry vs. two for traditional).[19-24] An inquiry-based laboratory was added to the earlier portion of the course to introduce the concept, replacing a practice lab practical, so inquiry was not a completely new process when the sphero-cylindrical ametropia labs were administered towards the end of the quarter.

The traditional sphero-cylindrical ametropia lab was taught for five years at AZCOPT for one laboratory period for a total of three hours. The lab began with a guided set of questions in response to which the students looked through or made observations about cylindrical lenses of various powers, combinations of lenses, pinholes and slits. They were asked to make a variety of observations including blur associated with points and extended objects, image movement, image formation and other simple observations. This introduction was followed by step-by-step instruction where students set up different sets of lenses on the optical rail. This included image formation with a single positive cylindrical lens and a

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variety of combinations of spherical and cylindrical lenses and screens to represent different types of regular astigmatism. For the eye models, students were also walked through the process of correcting these eyes with additional trial lenses.

Two inquiry-based laboratories on cylindrical and sphero-cylindrical lenses and sphero-cylindrical ametropia were implemented in addition to shortened versions of the traditional labs by increasing the time from one laboratory period to two. The new inquiry-based laboratories each included a traditional component and an inquiry component. All students received both approaches to the same content on the same day. To determine whether the order in which the two lab sections are offered matters for the learning outcomes, one section received the traditional lab first and the other received the inquiry-based lab first. These were immediately followed by the other component. The order was then switched the following week so all students experienced both orders to limit differences between groups.

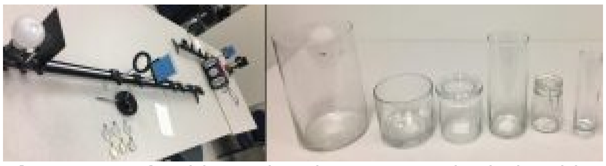

Figure 1. Left: This station demonstrated relationships between object and image distances, cylindrical lens orientation and image orientation. Right: This station used vases of various sizes filled with water to demonstrate relationships between index of refraction and curvature. Click to enlarge

Figure 2. Top left: This station used a model eye setup on the optical rail to demonstrate sphero-cylindrical ametropia and correcting lenses (glasses vs. contact lenses). Top middle, top right, top bottom: This station used eye models from Pasco to demonstrate phenomena related to sphero-cylindrical ametropia. A variety of options allowed the creation of various ametropic eyes: the ability to fill the eyes with water; objects on the optical rail or a computer; spherical and cylindrical lenses to act as the eye or correction; apertures to act as pupils; a moveable "retina" screen.
Click to enlarge

The inquiry-based labs were similar in format. In the first 15-20 minutes, students split into two to three groups to rotate through starter stations where they observed phenomena related to cylindrical and sphero-cylindrical lenses (week 1) and sphero-cylindrical ametropia (week 2). Each station began with a facilitator introduction to the station with demonstrations followed by time for the students to explore and discuss. The stations included:

Week 1: spherical and sphero-cylindrical lenses **(Figure 1)**:

1. Cylindrical and sphero-cylindrical lenses and image formation

2. Index of refraction and curvature

3. Looking through cylindrical and/or spherical lenses and slits/pinholes. Various +/- cylindrical and spherical lenses, pinholes and slits were provided from trial lens kits as well as near and distance eye chats and contrast charts

Week 2: sphero-cylindrical ametropia **(Figure 2)**:

1. Astigmatic eye models on optical rails and their correction

2. Pasco astigmatic eye models (https://www.pasco.com/prodCatalog/OS/OS-8477_human-eye-model/index.cfm)

3. Computer simulations of spherical and sphero-cylindrical imaging, e.g, sight simulator from prescription (http://www.billauer.co.il/simulator.html)

The students formed groups of three to four people in order to ask and refine a question and design and execute their own in-depth investigations into one aspect of cylindrical and sphero-cylindrical lenses (week one) and sphero-cylindrical ametropia (week 2). Members of each group presented their findings to the rest of the class in the final 20 minutes, as they had become the subject-matter experts. The total time for the inquiry-based lab component was approximately two hours.

A short quiz and survey were administered each week in the middle of the laboratory period after the first part of the lab was completed (either traditional or inquiry-based) to assess student knowledge and perception. Each lab was also followed by a quiz and survey in the next lecture for the same reasons. To ensure that any differences did not impact student assessment, the quiz scores were used exclusively as research data and did not count in the course grade. Students received full marks for finishing the quizzes and surveys. An analysis of the grade average and distribution was performed, and students were informed of any aggregate differences for their information.

The quizzes and surveys included several content-based questions. Students were asked to rate the lab they just completed (inquiry-based or traditional) in the middle of the lab period, and on the following day separately rate both labs on a scale of 1-10. Students were also asked about the impact of the lab(s) on their learning experience and about the order of the labs (only in class following both labs). They were asked opinion-based questions (rated disagree to agree) regarding their ability to solve basic and complex optics questions and if the lab enhanced their ability to solve problems and their conceptual knowledge. There were additional open-ended questions. An analysis was performed to assess student performance on these quiz/surveys.

Fifty-six students were enrolled for the first time in the OPTOG 1540 Geometrical and Physical Optics I course when two new inquiry-based laboratories were implemented in addition to traditional laboratories. All students participated in laboratories, quizzes and examinations as a part of the normal class activities. An analysis was performed to assess student performance on these quiz/surveys. Midwestern University IRB approval was received for this study (AZ #1075). Prior consent for disclosure of academic records was not required for this study, consistent with the Student Handbook, Appendix 3.D.2.g. Confidentiality was maintained and no names were used in the compiled data file. There was a risk of loss of privacy or breach of confidentiality, but a de-identified records review and data retrieval minimized such risks.

Results

The 56 students enrolled for the first time in the OPTOG 1540 Geometrical and Physical Optics I course participated in both new inquiry-based laboratories. They also completed traditional laboratories on the same day in a randomized order as described in the methods section. These were part of the requirements for the OPTOG 1540 Geometrical and Physical Optics I course. All 56 students completed the two survey/quizzes administered in the lab period, 52 students completed the in-class survey/quiz after the first week, and 55 students completed the in-class survey/quiz after the second week.

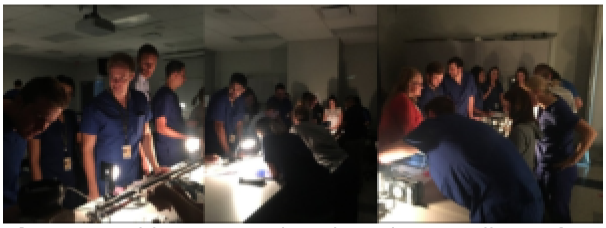

Figure 3. Midwestern University Arizona College of Optometry students at a starter station for the inquiry-based lab.
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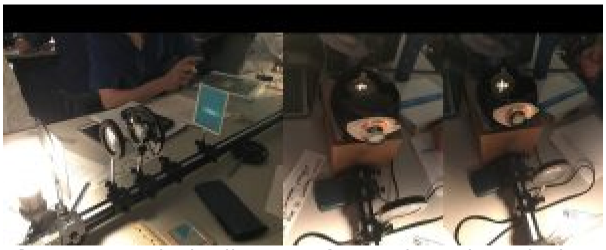

Figure 4. Optical rail setup of an astigmatic optical system (left). Eye models used with water (middle) and air (right) in an investigation of the impact of astigmatism on retinal blur. Click to enlarge

All students successfully participated in the starter stations and recorded vocabulary and questions. **Figure 3** illustrates students engaging with the starter materials. The entire group brainstormed questions together resulting in the investigation questions summarized in **Table 3**.

Students then proceeded with an investigation with the help of the instructor and facilitators. The inquiry labs culminated in the delivery of short presentations. Pictures from the investigations are shown in **Figure 4**.

During the first week's spherical and sphero-cylindrical lenses laboratories, 56 students completed a quiz and survey in lab immediately after either the inquiry-based lab (27) or the traditional lab (29). 52 students completed the quiz and survey in the next lecture. Results comparing performance on the four quantitative questions revealed no significant differences. Results comparing student ratings of the labs in their usefulness in gaining knowledge about cylindrical and sphero-cylindrical lenses on a scale of 1-10 in whole numbers where 1 is not useful and 10 is extremely useful also revealed no significant differences. These results are in **Table 4**. During the second week's sphero-cylindrical ametropia laboratories, 56 students completed a quiz and survey in lab immediately after either the inquiry-based lab (29) or the traditional lab (27). Fifty-five students completed the quiz and survey in the next lecture. Results comparing performance on the four quantitative questions and the questions asking students to rate the labs are presented in **Table 5**. There was again some variability, but no significant differences.

As discussed in the methods section, the survey included some open-ended questions. The responses to these questions highlighted the value of the diverse laboratory experiences. Selected responses are in **Table 6** and **Table 7**. In addition to the comments in the tables, numerous comments indicated the students would like more time; some felt they had to rush. This limitation of this first administration is addressed in the discussion section. Numerous comments highlighted that the students felt the traditional lab should take place before the inquiry-based lab, and many students requested more guidance.

TABLE 3
Questions for Inquiry-Based Laboratory Investigations

Week 1: Cylindrical and sphero-cylindrical lenses	Week 2: Sphero-cylindrical ametropia
• What happens when you combine sphere and cylinder lenses? • Where is the CLC using a sphero-cylindrical lens? • What is the impact of cylindrical and sphero-cylindrical lenses on image quality and image formation? • What happens when you change the axis of cylinder hitting the vase and how does this change our image formation? • What is the impact of sphero-cylindrical lenses on the conoid of Sturm? • What happens when you combine spherical and +/- cylindrical lenses? • What is the image formed at the CLC with different objects? • What is the difference between blur from a point and an extended object? • What is the role of the power and axis orientation? What is the role/use of @ and x?	• What happens to CLC with change in medium? • How does pupil shape change image quality? • What happens to the image with different mediums? • What is the size of the image with more or less astigmatism? • How does the magnitude of astigmatism impact the size of the CLC? • How does a myopic and a hyperopic eye affect image size? • How does accommodation impact astigmatism? • How does correction of astigmatism relate to powers of the eye? • How do different pupil sizes affect astigmatism along different axes? • How does the medium impact the Rx? • How do different combos of power and retina relate to classification of astigmatism?

CLC = circle of least confusion

Table 3. Click to enlarge

TABLE 4
Student Performance on Spherical and Sphero-Cylindrical Lenses Quiz and Lab Ratings

	Inquiry 1st In Lab Average (SD)	Trad 1st In Lab Average (SD)	Inquiry 1st In Class Average (SD)	Trad 1st In Class Average (SD)	Comparisons
Performance on four quantitative questions	2.6 (1.1)	2.8 (1.1)	3.0 (1.0)	2.9 (1.0)	p=0.81 (in labs) p=0.12 (lab/class inquiry 1st) p=0.52 (lab/class trad 1st) p=0.79 (in class)
Rate the **inquiry** laboratory activity this week in its usefulness in gaining knowledge about cylindrical and sphero-cylindrical lenses on a scale of 1-10 in whole numbers where 1 is not useful and 10 is extremely useful	7.3 (1.5)		7.0 (1.7)	6.1 (2.1)	p=0.12 (in labs) p=0.47 (lab/class inquiry 1st) p=0.26 (lab/class trad 1st) p=0.83 (in class 1st lab) p=0.58 (in class other lab) p=0.86 (in class inquiry lab) p=0.09 (in class trad lab)
Rate the **traditional** laboratory activity this week in its usefulness in gaining knowledge about cylindrical and sphero-cylindrical lenses on a scale of 1-10 in whole numbers where 1 is not useful and 10 is extremely useful		6.5 (2.2)	7.0 (1.5)	7.1 (1.6)	

Table 4. Click to enlarge

TABLE 5
Student Performance on Sphero-Cylindrical Ametropia Quiz and Lab Ratings

	Inquiry 1st In Lab Average (SD)	Trad 1st In Lab Average (SD)	Inquiry 1st In Class Average (SD)	Trad 1st In Class Average (SD)	Comparisons
Performance on four quantitative questions	2.1 (0.9)	2.3 (0.9)	2.4 (0.8)	2.5 (0.9)	p=0.85 (in labs) p=0.10 (lab/class inquiry 1st) p=0.18 (lab/class trad 1st) p= 0.70 (in class)
Rate the **inquiry** laboratory activity this week in its usefulness in gaining knowledge about cylindrical and sphero-cylindrical lenses on a scale of 1-10 in whole numbers where 1 is not useful and 10 is extremely useful.	5.5 (1.9)		6.0 (2.1)	6.7 (1.4)	p=0.19 (in labs) p=0.34 (lab/class inquiry 1st) p=0.38 (lab/class trad 1st) p=0.32 (in class 1st lab) p=0.45 (in class other lab) p=0.18 (in class inquiry lab) p=0.67 (in class trad lab)
Rate the **traditional** laboratory activity this week in its usefulness in gaining knowledge about cylindrical and sphero-cylindrical lenses on a scale of 1-10 in whole numbers where 1 is not useful and 10 is extremely useful.		6.1 (1.5)	6.3 (1.8)	6.8 (1.6)	

Table 5. Click to enlarge

TABLE 6
Selected Responses to Survey Questions During Lab and In-Lecture
(Week 1: Spherical and Sphero-Cylindrical Lenses)

What do you think the general impact of the lab was on your learning experience? Feel free to explain below.
• "When doing traditional labs it is much easier to focus more on the right answer and less on learning/grasping the material. Inquiry based makes it much easier to grasp the material."
What aspects/techniques used in this lab helped you in grasping the concepts?
• "Struggling on our own to answer a question helps you to really remember what you learned." • "Our presentation helped increase my knowledge about understanding the difference between vertical & horizontal. i.e. where power is in relation to axis." • "Having no "right answer" so I wasn't trying to complete it as fast as possible. Instead I strove for understanding." • "The inquiry lab and the presentations helped me grasp the big concepts."
Other comments (Say what you want to say)
• "I like the inquiry labs as it does help me with my understanding, but the presentation aspect is hard as struggling to put my conceptual understanding into words is difficult." • "Overall I like the inquiry labs. I think they help me to understand and grasp the concepts better." • "Inquiry based probably will be more memorable since we created our own experiment." • "I would like to do more inquiry lab and less of the normal lab." • "I really like the inquiry based lab and I think they help to increase my understanding of the lab."
What aspects/techniques would you like to see changed? (Please explain)
• "I feel like both labs should have been prior to lecture material. I feel like by the time we got to lab, I already had a good sense of the material & actually seeing it 1st in lab would have helped visualize it for lecture."

Table 6. Click to enlarge

TABLE 7
Selected Responses to Survey Questions During Lab and In-Lecture
(Week 2: Sphero-Cylindrical Ametropia)

What aspects/techniques used in this lab helped you in grasping the concepts?
• "Working through the traditional lab helped solidify my understanding." • "I really liked doing the traditional lab first. This way you get up to speed on concepts and start to find questions naturally as you work through the lab using the rail. Then, by the time the inquiry lab comes, you know more and already have some questions." • "The traditional lab helped me grasp the concepts, which then allowed me to use those concepts in the inquiry part of the lab." • "The new eye models are awesome! Nice to be able to test out our hypothesis to questions we may have."
Other comments (Say what you want to say)
• "The new eye models are awesome for really being able to understand vertical vs. horizontal blur by using computer images." • "I liked doing traditional first and then inquiry. This gave you a good basis before inquiry lab." • "Inquiry based lab made things more memorable than traditional."
What aspects/techniques would you like to see changed? (Please explain)
• "I would like some more structure." • "Doing a short traditional lab before an inquiry lab really helped my group coordinate how to carry out our experiment." • "I would always do the traditional lab first because it helps to go into the inquiry section with more understanding of the concepts and the math." • "A little more direction for the inquiry lab. Maybe premake questions so that they are less general and/or find a different system of choosing/assigning questions – so groups don't get stuck w/ a question that is either too hard, too confusing, or not what they wanted to inquire about." • "I personally liked doing traditional first to help build my foundation of knowledge so I know what to be inquiring about."

Table 7. Click to enlarge

Discussion

Inquiry-based labs are designed such that students will learn process skills relevant to optometric practice such as problem-solving, data analysis and communication along with the content goals. The new laboratories presented here centered on a difficult topic: cylindrical and sphero-cylindrical lenses and sphero-cylindrical ametropia. The goal of participating in these interactive laboratory sessions was for students to explore and develop a deeper understanding of the individual optical concepts and how they come together. Students also had the opportunity to participate in the traditional labs, which allows assessment of whether the inquiry-based approach would be best implemented before, after, or in place of the current teaching methods.

Although there was no statistical difference in the overall final exam grades or overall course performance, a number of outside course factors should be considered in order to evaluate the impact of the inquiry-based labs. The year without the inquiry-based labs had a laboratory practical examination prior to the written final examination. This resulted in a sequence such that the traditional astigmatism laboratory was completed weeks earlier in the quarter allowing more time for review prior to the final examination. The material was also examined prior to the final exam on the practical, hands-on examination. There were also some areas identified in need of improvement after the first implementation of the inquiry-based labs, specifically a lack of time to finish all parts of the labs that may have played a role in performance on these items. The true test will be students' future performance in upper-level courses and on the national board exam, which would make interesting follow-up studies.

It is extremely important for optometrists to be careful consumers of new technology. An increasing number of measuring and correcting devices are utilizing the knowledge of ocular aberrations in their design. It is not feasible to adopt all new equipment or work with all companies developing correcting devices. Therefore, having a deeper understanding of the vocabulary used and the patient populations for which this may provide maximum benefit is important for future success. Astigmatism is one of the most basic aberrations and ultimately one of the easiest to understand. Although many students already know how to transpose a prescription or have heard of astigmatism through personal experiences, the 3D and complex nature of the concepts related to sphero-cylindrical ametropia and its correction remain a challenge for many students. This is a topic they will see again in many classes and in practice, and an innovative approach to extending their knowledge early in their careers could be extremely meaningful and have long-reaching impact.

Preliminary results suggest some value in the addition of inquiry-based labs in an optometric setting. Some form of traditional instruction and/or laboratory demonstration may always be needed or at least enhance the experience. Many additions and revisions to these laboratories can be considered with the goal of an improved educational experience and enhanced long-term application of knowledge. One consideration is a variation on the hybrid experience whereby one week of traditional laboratory and one inquiry-based lab occur rather than a traditional and an inquiry component both occurring twice on two separate weeks. Other changes, such as submission of questions for investigation in advance through homework or a pre-laboratory activity or assignment, may simplify parts of the experience. Another consideration could be a different approach to the presentation of results such as having students deliver their presentations the following week or in class or completing some sort of laboratory report. Inquiry-based laboratories can often be more time-consuming for reasons that include the fact that students may face situations that are more challenging in which they feel stuck. Working through these elements can lead to greater ownership of the learning process and the development of useful skills for the future, but it requires more time and many of these suggestions address that. One consideration is that inquiry-based labs are extremely well-suited for strengthening and widening the scope of knowledge rather than introducing a topic.

Conclusion

New inquiry-based labs were introduced in the Geometrical and Physical Optics I course at AZCOPT. Students were put outside their comfort zone and extended their knowledge of astigmatism. The study implemented and utilized innovative teaching strategies in AZCOPT's optometry program. No statistical differences in exam or course performance were found with the use of traditional vs. inquiry laboratories. At least some form of traditional instruction seems to be required in order for students gain the maximum benefits from an inquiry-based laboratory. The results may inform program faculty regarding the implementation of other innovative teaching methods such as problem-based learning, a flipped classroom, etc. Finally, the results may provide additional evidence to guide educational practices for optimal outcomes on the national certification examination.

Acknowledgments

We thank the Institute for Scientist and Engineer Educators (ISEE) for providing professional development in inquiry teaching that has significantly influenced this work. Thank-you to Alicia Feis, OD, FAAO, Joshua Baker, OD, and Balamulari Vasudevan, BSOptom, PhD, FAAO, for their administrative support. Thank-you to Shari Burns, EdD, CRNA, for her help in project development. Thank-you to ASCO for the support it provided through an Educational Starter Grant.

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