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The Practical Optics Workshop: Educating the Optical Engineers of Tomorrow

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ABSTRACT

A comprehensive education of optical engineers is of paramount importance to the development of the industry. While optical sciences and engineering curricula are set up to teach theoretical concepts comprehensively, there appears to be a lack of required coursework that teaches students how to use industry-standard software that they will inevitably use in their careers. The Practical Optics Workshop (POW) is an initiative at the University of Arizona's Wyant College of Optical Sciences to support the education of students that use optical design software. POW's aim is to bridge the gap between the theory of optical system design and the problems the optical engineers of the future will face daily. POW has principally engaged students through short workshop sessions and optical design problems through inquiry-based learning activities. However, during the COVID-19 pandemic new activities have been designed to support self-paced and virtual learning to ensure the accessibility of Optical Design software education. We present the status of POW's current initiatives and how they have impacted student learning, as well as the design of future initiatives that POW is developing for a self-paced curriculum.

1. INTRODUCTION TO POW

The Practical Optics Workshop (POW) is a student-lead organization at the University of Arizona's Wyant College of Optical Sciences charged with the mission of providing early career professionals with optical engineering tools that aren't taught in coursework. The group traces its origins to an initiative begun by our advisor, Dr. Daewook Kim. Dr. Kim once offered lessons in optical design software and metrology techniques to members of industry. Optical Engineering companies would pay to send their optical engineers to be trained at the University of Arizona during a seminar that covered one or more topics that would develop general optical engineering skills. Later on this idea was revived by a group of students, with the intention of circumventing the expensive training by providing it when students of the Wyant College of Optical Sciences were enrolled in their degree program.

The mission of POW series is to fill the gap between scientific understanding of optics principles and practical implementation. Many tasks, such as safe handling of optical components or working with commercial interferometers are used daily in optical science and engineering tasks, but are seldom covered in academic classes taught at the University of Arizona's College of Optical Sciences. POW conducts a series of workshops focused on developing hands-on skills for the future generations of optical engineers.

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POW is principally composed of student volunteer tutors. The tutors are trained on industry-standard optical design software (e.g. CODE V,[1] Zemax OpticStudio,[2] etc.) and metrology methods (e.g. Zygo, 4D interferometers) such that they are sufficiently qualified to lead workshop sessions that are instructive to the students of the Wyant College. These workshop sessions are a mix of general instruction and inquiry-based activity to engage the attendees and solidify basic optical engineering practices.

In these proceedings we report on the status of POW immediately before, during, and after the COVID-19 pandemic. In section 2 we review the state of optical design education at the University of Arizona and the support of POW by industry sponsors. In section 3 we explain the workshop model of instruction and how it evolved in response to the COVID-19 imposed quarantine order. In section 4 we show how POW has impacted student learning at the Wyant College of Optical Sciences. In section 5 we outline our plans for future developments in POW and lessons learned from the COVID-19 pandemic.

2. OPTICAL DESIGN SOFTWARE EDUCATION

2.1 Review of Curricula at the Wyant College of Optical Sciences

For undergraduates pursuing a Bachelor's of Science in Optical Sciences and Engineering, there are two undergraduate courses that covers raytracing software. *OPTI 340 - Optical Design* is an excellent introduction to the theory of optical system design. However the course is conducted entirely using the CODE V sequential raytracing package and taught with isolated examples, rather than a comprehensive overview of the software. This course is a requirement for graduation, so all undergraduate students are exposed to at least one sequential raytracer in their coursework. *OPTI 485 - Illumination Engineering* is also a highly comprehensive course detailing the theory of illumination design and radiometry using a project-oriented framework. Students propose a project at the beginning of the semester and they spend the remainder of the semester elaborating on the project and learning how to build up the model and/or design process. Conversely, this class permits use of any non-sequential raytracing software (ASAP, FRED, OpticStudio, LightTools). The software instruction is limited to a single software example per week. Any other assistance with the software is acquired by scheduling one-on-one appointments with the instructor of the course.

Graduate students pursuing a Masters of Science or Doctor of Philosophy in Optical Sciences have more options with regard to optical design education as technical electives, but these classes face the same challenge as the aforementioned undergraduate courses. How must a professor complete their course material *and* provide a comprehensive overview of all of the industry-standard software packages that optical engineers use on a daily basis? There is simply too much important theory in a given course to allocate valuable lecture time to comprehensive education about the optical design software, so the education must happen outside of class time.

This is where POW comes in. POW tutors are trained directly by the companies who develop optical raytracing software to be certifiably ready to provide the same instruction to students of the Wyant College. By doing so POW can consistently help students build software fluency so that they are more prepared to utilize these tools when they enter industry. Through the generous sponsorship of our industrial affiliates, POW succeeds at filling the void left in most optical design courses by diving deep into the effective use of software, assisting the College in its mission to educate the next generation of exceptional optical engineers.

2.2 Sponsor Support of Curriculum Development

The primary sponsors of POW are Synopsys®, the makers of software such as CODE V[1] and LightTools, and Ansys Zemax®, the developers of OpticStudio[2] and OpticsBuilder, among other tools. POW also receives training from LightTrans® on the use of their physical optics software, VirtualLab Fusion.[3] Through close collaboration with these sponsors, POW tailors the curriculum presented during workshops to match the intended learning goals provided by the software vendors with the hope of maximizing the marginal value provided to each sponsor through their ongoing collaboration with POW. By maintaining this focus on maximizing benefit to sponsors, POW has been successful at fostering a positive working relationship with each contact, enabling future growth of the program and innovation on current best practices. In turn, the extensive tutorial support provided to POW tutors by the dedicated team members at Synopsys, Ansys Zemax, and LightTrans has significantly enhanced the impact POW has on optical design education at the Wyant College, as will be discussed in § 4.

3. POW INITIATIVES

Figure 1. A typical POW Workshop in progress. We encourage inquiry-based learning activities lead by one tutor (left) with the rest of the team offering technical support as the workshop is lead through examples. We also provide pastries and coffee (when it is safe to do so) for our attendees, as we have found that they tend to ask more questions when well fed and caffeinated.

3.1 Workshops

Workshops are POW's primary mode of instruction. A typical workshop environment is shown in Figure 1. In workshops, students learn how to use optical design software from tutors who lead the attendees through examples that illustrate multiple key features of a given software package. Prior workshops have covered various levels of topics for beginners (*i.e.*, 'Intro to OpticStudio', 'Intro to CODE V' and more) to advanced level users (*i.e.* Application programming interface for OpticStudio, 'A CODE V Cafe - Optimization' and more). Generally, six workshops are hosted per semester, each with a running time of about two hours. A sampling of some recent workshops is included in Table 1, along with exemplary flyers used to advertise the workshops and tutoring services shown in Figure 2. We continue to develop new workshop content, providing attendees with fresh insights and useful tools for optical analysis. In the near future, we plan to initiate a broader range of workshops for the varied courses of study within our College of Optical Sciences.

Zemax Workshops	Intro to Zemax OpticStudio: Sequential Intro to Zemax OpticStudio: Non-Sequential Intro to Tolerancing in OpticStudio Intro to Optimization in OpticStudio Intro to OpticsBuilder Advanced Topics in Zemax OpticStudio: Coordinate Breaks Advanced Topics in Zemax OpticStudio: Intro to ZOS-API
Synopsys Workshops	CODE V Café: An Introduction to CODE V LightTools and Lattes: An Introduction to LightTools Advanced Topics in CODE V: Macro-PLUS Optimization and Zooms Advanced Topics in CODE V: Unobscured Mirror Design with jmrcc
Zygo MetroPro	Intro to Optical Shop Testing

Table 1. Matrix of prior workshops sorted by company.

Figure 2. Flyers advertising past POW workshops. POW provides software-centric workshops, practical optics seminars, and one-on-one tutoring sessions.

The introductory workshops for software emphasize a few key details.

- Use cases for the optical engineering software package
- Introduction to the graphical user interface
- Statement of a specific design problem
- Aspects/uses of the software we aim to understand better through the workshop

The workshops are designed to prominently illustrate a particular feature of the design code used for instruction. For example, in our *Intro to Zemax OpticStudio: Sequential* workshop we have the users design a plano-convex singlet to collimate an LED onto a lightpipe over a given collection area. During the course of the workshop, the attendees are introduced to the System Explorer, Lens Data Editor, the Optimization Wizard, Analysis tab, and the Off-the-shelf Lens import tool (Lens Catalog). We practice care when structuring these workshops to not inundate the attendees with excessive information about software features, but rather opt to demonstrate clear examples of software basics to provide a strong foundation for future learning.

3.2 One-on-One Tutoring

Beyond the software training presented during workshops, POW provides one-on-one tutoring to students. Tutoring sessions are uniquely positioned to assist students working on research projects, or those requiring the use of an advanced software feature. Students make an appointment to meet individually with a POW tutor using a Setmore clander for scheduling. Because students using academic software licenses have limited access to technical support, POW tutors serve as an essential support network to enhance proficiency and answer complex optical analysis questions in intricate detail. Furthermore, POW tutors are recognized as experienced peers, which can greatly reduce social anxiety for students who would otherwise be too timid to ask for help, e.g. from a professor during office hours or during a lecture. By means of this peer-to-peer network of optical design knowledge transfer, the young optical scientists of the Wyant College serve to gain a great deal of experience by through collective learning.

3.3 Practical Optical Design Seminar

The Practical Optical Design Seminar (PODS) was an initiative that aimed to teach students how to use optical design programs through inquiry-based research activities. PODS is meant to advance the learning of students that already had experience with optical design software, and undertake research-level investigations to explore the limits of what is achievable with the software. The first generation of this program began with 5 students and one student leader that pursued an optical design survey of CubeSat objectives. This began with the students devising optical design specifications from a literature review on CubeSat objectives, and learning the basics of designing simple two-mirror objectives (Cassegrain, Gregorian, Schwarzchild). These investigations included exploring the aberrations of these systems, and how to program tools that automate the design process using OpticStudio and CODE V's macro languages. The PODS group met weekly to discuss the designs that they had been working on and revise their investigation.

3.4 Influence of the COVID-19 Pandemic

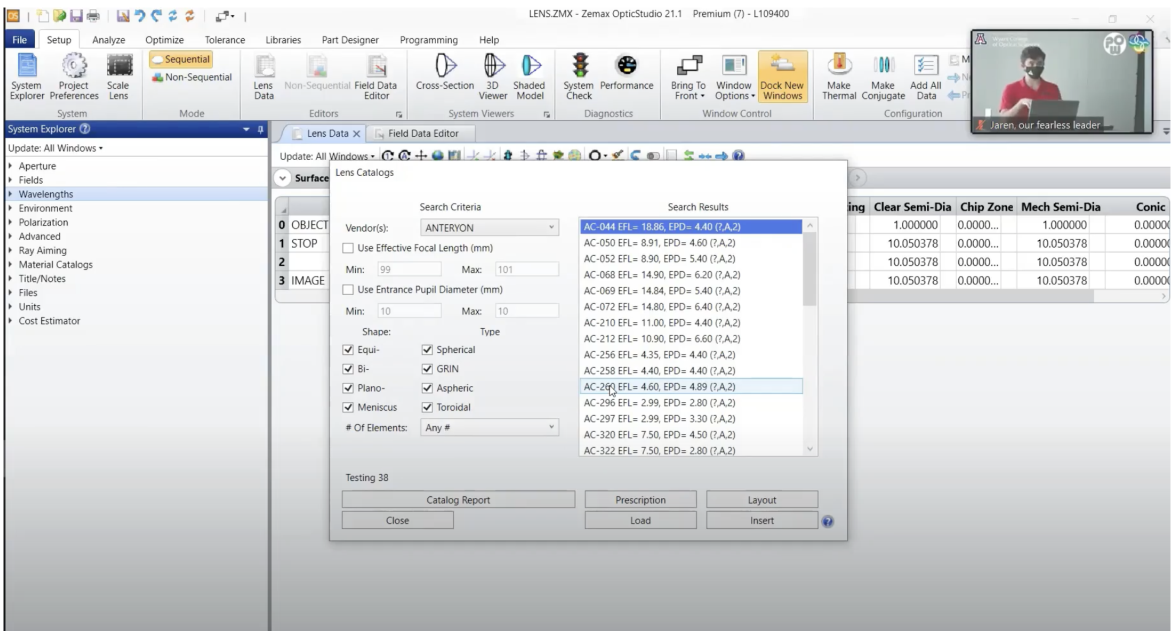

Figure 3. After the beginning of the COVID-19 Pandemic POW switched to an online-only format where all workshops were conducted using Zoom®. The application of this technology enabled easy recording of the entire workshop and made the program more accessible to remote students.

In the Spring semester of 2020, POW faced a great challenge with the onset of the COVID-19 global pandemic. During this time, POW switched to entirely online workshops offered via Zoom®. This experience was somewhat jarring for the tutors, because we were used to the direct interaction that the in-person workshop experience enabled. To accommodate for the change in learning environment our teaching style had to change as well. We piloted the instructional style with a workshop that walked through the development of an optimization macro step-by-step and gave ample time for the workshop attendees to play with different parameters to see how they influenced optimization. At each step the attendees were asked to show off what their investigation lead to. This meant that less content could be covered in a short amount of time, but we observed better retention of the information and more engagement in the actual workshop. In summation, we leaned further into the inquiry-based learning platform and also asked the attendees to participate actively. This method was refined in the Advanced workshops until the tutors felt comfortable with a comprehensive Introductory workshop that was suitably engaging over zoom. The result was a very active and comprehensive exploration of a key industry-standard optical design software.

Because of the COVID-19 pandemic POW progressed to a hybrid teaching platform, where workshops were offered both in-person (with masks and social distancing) and online. An example of a hybrid in-person/Zoom®

workshop is shown in Figure 3. The insights provided by our time performing remote workshops during the COVID-19 pandemic allowed us to produce more engaging workshops for remote participants. Now, POW can reach all students of the Wyant College of Optical Sciences, even if they conduct their studies remotely.

4. POW IMPACT ON STUDENT LEARNING

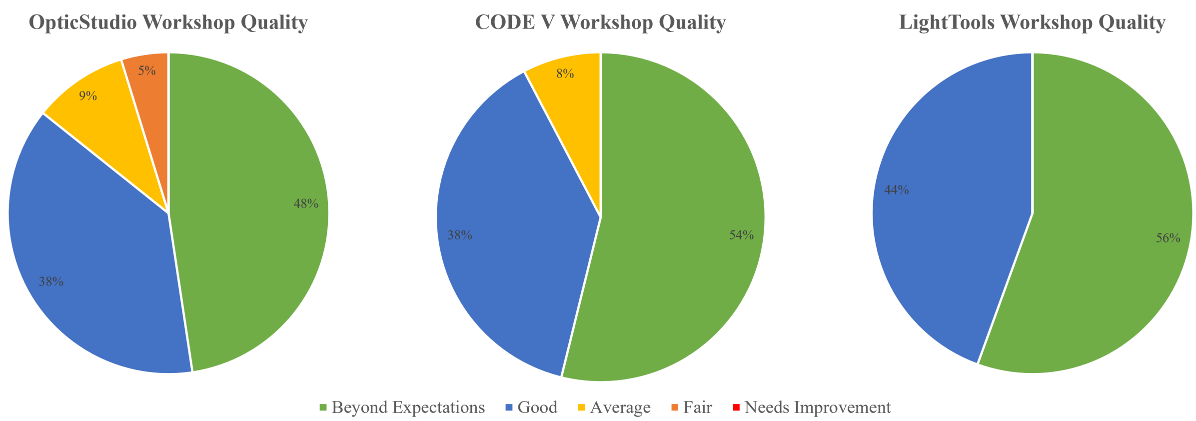

Figure 4. Student perception of workshop quality separated by design code between 2019 and 2021.

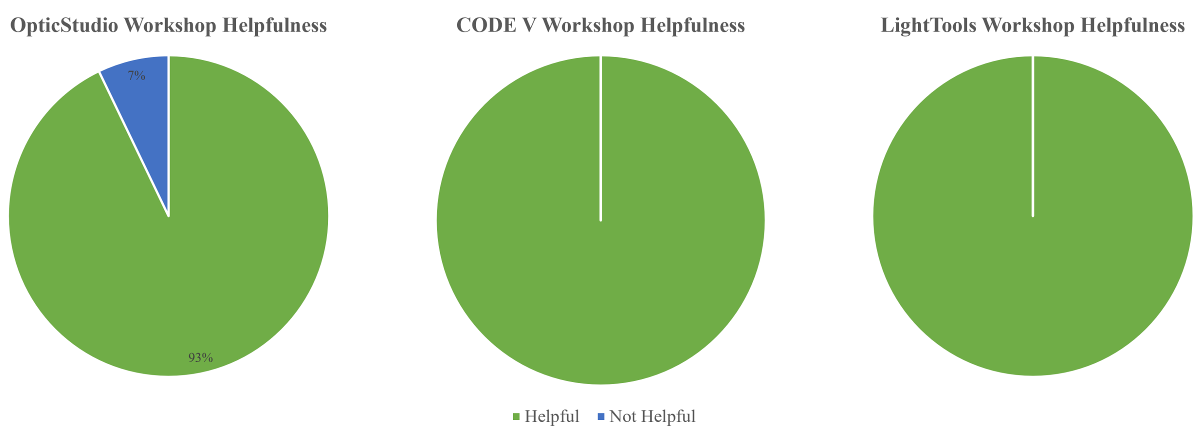

Figure 5. Student perception of workshop helpfulness separated by design code between 2019 and 2021.

4.1 Student Perception of Workshop Quality

In general, students are very grateful for the services offered by POW and have expressed their gratefulness with consistently positive feedback. Students have indicated to our tutors that they would have been unable to accomplish the optical design tasks they were assigned with if not for the extensive background provided through both attendance of POW workshops and one-on-one tutoring. Evidently, the educational opportunities provided by POW are essential to the flourishing of young optical scientists and researchers as they begin their careers.

4.2 How Beneficial is POW?

Analytics provide incontrovertible evidence of the massive impact POW has on students at the Wyant College of Optical Sciences and on the optics community at large. POW tutors make a point of collecting qualitative and quantitative data at each of our POW workshops alongside candid feedback provided by students following the conclusion of each workshop. Though not all feedback is positive, the vast majority of the feedback provided by attendees demonstrates an out-sized positive sentiment towards the great effort exhibited by POW tutors to provide only the highest-quality workshops.

4.3 Analysis of Qualitative Feedback

The charts in Figures 4 and 5 indicate the distribution of responses by students when queried about the quality and the helpfulness of workshops, illustrating the largely positive qualitative feedback provided by students. Thanks to the great care POW tutors take to methodically and carefully explain optical design concepts and techniques, many students come away having benefited greatly from investing time in POW's services, and most return for future workshops and bring friends along with them. Though this positive feedback loop was somewhat hampered by the pandemic, resulting in very little data collected in 2022, POW is steadily recovering from the general drop in attendance and participation as students re-integrate into in-person learning.

5. POW IN THE FUTURE

The lessons learned from the origin of POW, as well as what we learned from the COVID-19 pandemic have changed the vision for the organization. In lieu of the in-person workshop experience we embraced the possibilities for greater reach that asynchronous instruction has to offer.

5.1 Worksheets

The worksheets initiative began with the increase of digital learning that arose during the COVID-19 pandemic. After migrating our workshops and one-on-one tutoring sessions to an all-digital format we noticed a dramatic decrease in overall workshop attendance. To make our instruction more available

Asynchronous learning became very prominent in 2020 with the rise of the COVID-19 pandemic. The University of Arizona's Wyant College of Optical Sciences had implemented this style on a class-by-class basis, particularly for online students. POW's prior workshop-oriented structure relied deeply on direct interpersonal interaction between tutor and student, which migrated poorly to the post-COVID world. To simultaneously future-proof POW to this style of education and make the group's resources more accessible, we are slowly trying to develop an asynchronous curriculum for each optical modeling software we support.

This asynchronous curriculum currently quite nebulous, and is largely composed of a loose collection of tutorials, mimicking the Zemax Knowledgebase format. In the future we aim to develop a self-paced curriculum that is based on a series of practically applicable examples. Below are examples of tutorials that have been made by previous POW tutors:

- Modeling Off-axis Conics in Zemax OpticStudio
- Gaussian Beam Propagation in Sequential Raytracers
- Method of Confocal Mirror Design

The primary difficulty in assembling these worksheets is the effort required to draft and update them. POW is entirely composed of students who volunteer their time to instruct their peers on practical optical engineering techniques, while also conducting research and coursework full-time. Consequently the worksheets need to be fairly complete before distributing them to the public.

Another interesting but unexplored realm of design software is open-source physical optics modeling tools. In the diffraction-limited regime optical imaging is typically well-represented by Fourier-transform based propagation methods in the small angle approximation (e.g. Fraunhofer, Fresnel diffraction).[4] Most commercial optical design packages support coherent modeling to some degree but for those requiring open-source tools several exist for modeling diffraction-limited optical systems. POPPY (Physical Optics Propagation in Python)[5] is an open-source, object oriented python library that supports Fraunhofer and Fresnel diffraction calculations. It was originally developed as the physical optics engine of WebbPSF, a tool for simulating the point-spread functions of the James Webb Space Telescope. POPPY is generally supported by a team at the Space Telescope Science Institute and has been used for analyzing astronomical telescopes. HCIPy (High Contrast Imaging for Python)[6] is a similar library developed by Por and has a great diversity of functionality. In addition to scalar diffraction modeling it supports polarization, fiber coupling, adaptive optics simulation, and many other useful tools.

6. CONCLUSION

In this manuscript we present the historical, ongoing, and future ventures undertaken by the Practical Optics Workshop team to provide students of the Wyant College of Optical Sciences with the support needed to overcome their practical optics challenges. Through comprehensive software education during engaging workshops, instructive one-on-one tutoring, and interactive seminars, POW serves the greater optics community by providing early-career optical scientists the skills needed to flourish. The positive impact POW has on the students of the Wyant College of Optical Sciences is clear and we look forward to developing the program to be even more beneficial.

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