Bridging Theory and Practice
Enhancing Graduate Optics Education with Simulation-Driven Learning

Parnell, H.; Cooke, S.; Bociort, F.

DOI
10.1109/ETOP64842.2025.11030693

Publication date
2025

Document Version
Final published version

Published in
2025 IEEE Conference on Education and Training in Optics and Photonics, ETOP 2025 - Proceedings

Citation (APA)
Parnell, H., Cooke, S., & Bociort, F. (2025). Bridging Theory and Practice: Enhancing Graduate Optics Education with Simulation-Driven Learning. In *2025 IEEE Conference on Education and Training in Optics and Photonics, ETOP 2025 - Proceedings* (2025 IEEE Conference on Education and Training in Optics and Photonics, ETOP 2025 - Proceedings). IEEE. https://doi.org/10.1109/ETOP64842.2025.11030693

Bridging Theory and Practice: Enhancing Graduate Optics Education with Simulation-Driven Learning

H. Parnell[1], S. Cooke[1] and F. Bociort[2]

1. Ansys, Southpointe 2600 Ansys Drive, Canonsburg, PA 15317 USA
2. Faculty of Applied Sciences, Delft University of Technology
harriet.parnell@ansys.com

2025 IEEE Conference on Education and Training in Optics and Photonics (ETOP) | 979-8-3315-4301-3/25/$31.00 ©2025 IEEE | DOI: 10.1109/ETOP64842.2025.11030693

***Abstract*— *Graduate optics education requires a balance between theoretical rigor and practical application to equip students with the skills demanded by an evolving industry. This paper explores the integration of simulation-driven learning into optics curricula, emphasizing its role in bridging theoretical concepts and real-world applications. A case study from Delft University of Technology highlights the use of Ansys Zemax OpticStudio® in Dr. Florian Bociort's "Geometrical Optics" course. The study shows how interactive tutorials, such as a Cooke triplet lens design, enhance understanding of optical aberrations, lens optimization, and system performance. Additionally, this paper outlines the resources provided by the Ansys Academic Program, including software access, curated tutorials, and faculty development initiatives, which empower educators and students. By integrating advanced simulation tools, this approach not only fosters technical proficiency but also prepares students for the challenges of modern optical engineering.*

***Keywords*—simulation, Ansys Zemax OpticStudio, curriculum, Cooke triplet, optimization**

I. Introduction

Geometric optics plays a fundamental role in graduate optics education [1], [2], providing the basis for understanding critical concepts such as image formation, optical aberrations, lens design, and system optimization. These topics, often grounded in complex mathematical models, can be difficult to grasp through theoretical instruction alone [3]. Simulation-driven learning has become an invaluable addition, offering interactive, visual tools that enhance comprehension and make abstract principles more accessible.

As the field of optics evolves rapidly, the demand for professionals skilled in designing, analyzing, and optimizing sophisticated optical systems continues to grow [4], [5], [6]. Meeting this demand requires a curriculum that balances strong theoretical foundations with hands-on experience. Simulation software plays an important role in this balance, enabling students to visualize, test, and refine optical designs in a controlled virtual environment [7]. These tools not only help clarify the impact of aberrations and the performance of optical systems but also provide practical training that bridges the gap between conceptual understanding and real-world application.

This paper explores the value of simulation-driven learning in graduate optics curricula, emphasizing its role in linking theory with practice. It presents a case study of Dr. Florian Bociort's tutorial for the AP3391 Geometrical Optics course at Delft University of Technology, now available as an Ansys Education Resource. The study highlights how simulation tools enhance learning by offering hands-on experience in lens design and aberration correction. The paper also discusses Ansys' Academic Program, which supports such initiatives through software access, training, and industry collaborations, demonstrating how strategic partnerships enhance optics education.

II. The Educational Value of Simulation-Driven Learning

Simulation-driven learning provides an interactive and realistic approach to mastering complex optical design concepts. It enhances student learning by enabling active engagement with theoretical models through real-world applications. Some key educational benefits include:

A. *Addressing Learning Gaps*

Traditional optics instruction often involves detailed theoretical explanations and analytical problem-solving. While these are essential, they can sometimes limit students' ability to intuitively grasp complex optical behavior, especially since students may come from diverse academic backgrounds, such as physics, electrical engineering, and mechanical engineering. Physical lab experiments offer valuable opportunities to bridge the gap between theory and application. However, their effectiveness is often constrained by the availability of institutional resources and the inherent restrictions on the scope and adaptability of experimental setups. Simulation-based learning addresses these challenges by providing a versatile and resource-efficient complement to analytical instruction and physical labs. By enabling students to engage with real-time models and explore a broader range of scenarios—including those impractical or unattainable in physical experiments—simulations deepen their understanding and strengthen the connection between theoretical principles and observable system behavior.

B. *Benefits of Industry-Standard Simulation Tools*

As well as supporting foundation learning, industry-standard tools such as Ansys Zemax OpticStudio®, an optical system design and analysis software, provide students with practical skills directly applicable in the workforce. These tools allow students to visualize how theoretical models translate into real-world optical systems, giving them a deeper understanding of both theory and application. Students can also strengthen their problem-solving abilities by engaging in iterative design processes, gaining hands-on experience in designing, testing, and optimizing systems. Familiarity with these professional tools enhances students' technical proficiency, preparing them for the demands of the industry and improving their career prospects.

C. Balancing Theory and Simulation

While simulations offer valuable learning experiences, they cannot replace core theoretical instruction. Balanced integration ensures simulations enhance understanding without undermining foundational concepts. Key opportunities for effective integration include:

- Contextual Integration: Introduce simulations after foundational theory to reinforce learning and facilitate practical application.
- Critical Analysis: Encourage students to compare simulation results with theoretical predictions or experimental results, fostering deeper understanding and critical thinking.
- Analytical Rigor: Use simulations to explore edge cases, verify analytical models, and challenge assumptions, which strengthens students' problem-solving skills.
- Capstone Projects: Incorporate simulations into final design projects, where students apply both theoretical knowledge and practical skills to solve real-world problems.

III. CASE STUDY: THE COOKE TRIPLET

A. Geometrical Optics AP3391 at TU Delft

At Delft University of Technology, Dr. Florian Bociort integrates a one-hour demonstration of optical system optimization using OpticStudio into his master's-level course, "Geometrical Optics" (AP3391). The session is structured in two parts.

The first employs the Double Gauss example, available in the optical element library, to introduce the foundational data required to construct an optical system in the software. This includes lens parameters such as the number and type of surfaces, their corresponding radius, thickness, material, and overarching design specifications like aperture, field, and wavelength. Dr. Bociort explains how the software traces rays through the system and concludes this segment by analyzing image quality using built-in diagnostic tools.

The second part of the demonstration focuses on designing an optimized system, using the Cooke triplet example as inspiration. This three-element lens is ideal for teaching optical design, as it combines simplicity with practical depth, allowing students to explore key principles such as correcting aberrations through adjustments to lens parameters [8]. It is manageable for beginners and illustrates real-world applications.

Reflecting on his experience, Dr. Bociort states, "I will continue to teach this example in the same way. My students are excited about integrating computer simulations with the theoretical aspects of the course. They uncover properties of optical systems that are difficult to grasp through theory alone and recognize that simulation is an essential practical tool in modern optical system design". Moreover, his use of this example extends beyond academia, having employed it in an industrial training program, SMETHODS [9], between 2011 and 2015. This dual application underscores the versatility and practical relevance of OpticStudio in both educational and professional contexts.

B. Ansys Education Resources

Ansys Education Resources support university educators in integrating advanced simulation tools into their curricula. Spanning disciplines such as mechanical, materials, electronic, and optical engineering, these resources—developed by Ansys experts or in collaboration with academia—include case studies, lecture units, exercises, and tutorials. Designed for seamless curriculum integration, they align with modern pedagogical approaches to enhance student engagement and connect theory with practice.

Dr. Bociort's teaching example inspired the creation of a new Ansys Education Resource, focused on the optimized Cooke triplet, to support universities around the world who wish to bolster their Optics teaching in this way [10]. Titled "Reducing Aberrations with Ansys Zemax OpticStudio® Software," this tutorial provides educators with a structured teaching resource to guide students through the lens design process using the Cooke triplet in OpticStudio. As part of the tutorial, students learn the basics of using the software, and by the end of it should be able to:

- Set up an optical system in the Sequential Mode of OpticStudio software.
- Evaluate system performance using available analysis tools.
- Understand basic optimization concepts, including setting variables and using the Merit Function Editor.

As demonstrated in the AP3391 course at TU Delft, this tutorial can be integrated into a curriculum as a one-hour lab demonstration. For programs with limited syllabus flexibility, it is also designed to support independent learning, ensuring accessibility outside formal instruction.

Following the iterative workflow of setup, analysis, and optimization, an overview of the tutorial is provided below:

a) Stage 1: Review system specifications. The tutorial begins with an F/5 singlet lens made of SK16 glass, intended as a photographic objective. The goal is to develop a final design that meets the specifications and constraints outlined in Table 1.

b) Stage 2: Setup system parameters and lens data. Users input the system specifications into OpticStudio, guided by step-by-step instructions and screenshots. An example is given in Fig. 1. Reflective prompts, such as "What kind of material is SK16?" encourage deeper understanding, with answers provided in the notes section.

TABLE I. OPTICAL LENS SYSTEM SPECIFICATIONS FOR THIS TUTORIAL.

Specification	Constraint
Focal length	5 mm
Entrance Pupil Aperture	10 mm
AFOV	20 degrees
Wavelength	F, d, C preset
Object location	At infinity
Optimization criteria	RMS Spot Size average over AFOV

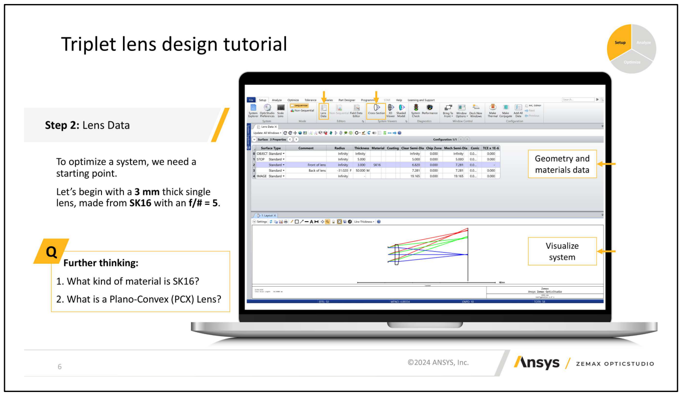

Fig. 1. Slide taken from "Reducing Aberrations with Ansys Zemax OpticStudio® Software" Ansys tutorial, demonstrating how to import lens data into OpticStudio.

c) Stage 3: Analyze the initial system. Tools such as the spot diagram, image simulation, Ray Fan plot, and OPD Fan plot are used to evaluate the performance of the initial system. Each tool is briefly introduced, with key insights from the results summarized. An example is shown in Fig. 2.

d) Stage 4: Optimize the system. The tutorial introduces more parameters to refine the design, transitioning from a singlet lens to a three-element system with two air gaps. Learners define the initial configuration, assign variables and constraints, and select a merit function. Incremental adjustments are demonstrated to show progressive improvements, culminating in an automated optimization step that produces a final design resembling the Cooke Triplet.

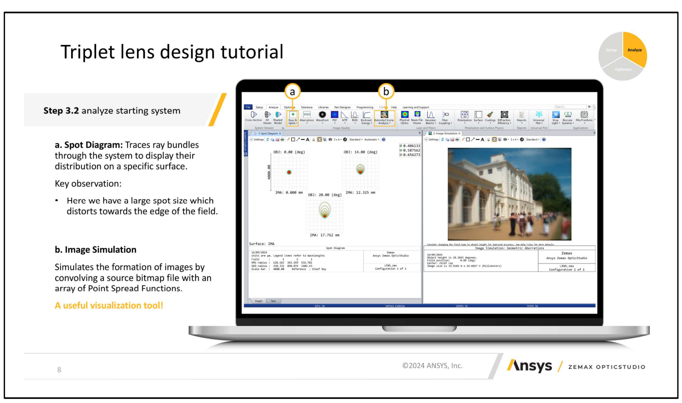

Fig. 2. Slide taken from "Reducing Aberrations with Ansys Zemax OpticStudio® Software" Ansys tutorial demonstrating how to analyze the starting optical lens system in OpticStudio. Here the spot diagram and image simulation results are shown.

IV. Supporting Academic Excellence: Ansys' Academic Program

A. Program Overview

Beyond the development of Ansys Education Resources, the Ansys Academic Program aims to advance engineering education by providing students, educators, and researchers with access to advanced simulation tools, resources, and professional development opportunities. With dedicated teams supporting academic institutions, the program includes several initiatives, three of which are outlined below.

B. Key Initiatives

a) Software Access: The Ansys Academic Program provides academic institutions with easy access to Ansys' full suite of engineering simulation tools, including OpticStudio. Three types of licenses are available: licenses for **General Academic Use**, a commercial-grade version of the software available at a significant discount for Research or Teaching; the **Student Design Teams License**, a free, full commercial-grade license provided through academic partnerships for student design teams; and the **Student Version**, a free, easy-to-setup version with limited capabilities, ideal for self-learning, class projects, and certification, and restricted to personal laptops. Student versions of flagship Ansys software have been available for many years, and are now joined by OpticStudio Student (www.ansys.com/academic/students/ansys-zemaxopticstudio-student) to further support student self-learning in the Optics field.

b) Faculty Development: Ansys offers several tools to support educators in enhancing their teaching. These include the **Educator Hub**, which connects hundreds of resources, such as Ansys Education Resources, focused on various teaching topics; the **Ansys Academic Webinar Series**, which explores strategies for strengthening curricula, providing hands-on learning experiences, and improving student retention; and the **Ansys Funded Curriculum** initiative, where educators can submit innovative curriculum ideas or course improvements that include Ansys software, with successful proposals receiving grants of up to $25,000.

c) Student Engagement: Ansys is dedicated to preparing students for future success by offering free **Ansys Innovation Courses**, access to the **Learning Forum** support community, and a wide range of student-focused tutorials. For students with a competitive edge, Ansys also supports teams in competitions such as Formula SAE (FSAE), Solar Challenge, Electronic Design Competition, Solar Splash, and many others.

V. Conclusion

Simulation-driven learning has emerged as a transformative approach in graduate optics education, effectively bridging the gap between theoretical instruction and practical application. The case study from Delft University of Technology demonstrates how tools like OpticStudio enable students to visualize, design, and optimize optical systems, fostering a deeper understanding of key concepts such as aberration correction and lens design. The integration of simulation tools, complemented by resources like Ansys Education Resources, aim to enhance student engagement and learning outcomes while aligning academic training with industry demands.

Ansys Education Resources are one aspect of the Ansys Academic Program, which provides access to cutting-edge software, curated teaching materials, and professional development opportunities for educators supporting educators to amplify their impact. By embracing industry technologies, where they are supported for academic use in this way, institutions can cultivate a generation of optics professionals who are not only theoretically grounded but also proficient in applying advanced technologies to solve real-world challenges. This paradigm shift in education underscores the potential of strategic partnerships in shaping the future of optics training.

REFERENCES

[1] M. L. Dark, "Developing technical and soft skills in an introductory optics course," in *Seventeenth Conference on Education and Training in Optics and Photonics: ETOP 2023*, Optica Publishing Group, 2023, p. 1272314. doi: 10.1117/12.2670570.

[2] M. L. Dark and C. M. Merriweather, "Student Learning through Independent Projects in Introductory Optics," in *Education and Training in Optics & Photonics Conference 2021*, Optica Publishing Group, 2021, p. W4A.5. doi: 10.1364/ETOP.2021.W4A.5.

[3] N. Nasser, E. Khouzai, and A. Zahidi, "Geometrical optic learning difficulties for Moroccan students during secondary/university transition," *International Journal of Evaluation and Research in Education (IJERE)*, vol. 10, p. 24, Mar. 2021, doi: 10.11591/ijere.v10i1.20639.

[4] C. Joenathan, S. C. Granieri, A. Siahmakoun, H. Alisafaee, and S. A. Reza, "Thirty-five years of optics education at Rose-Hulman: from optical sciences to optical engineering - 3 cycles of ABET accreditation," in *Seventeenth Conference on Education and Training in Optics and Photonics: ETOP 2023*, Optica Publishing Group, 2023, p. 127231Q. doi: 10.1117/12.2670793.

[5] O. Vauderwange, D. Curticapean, U. Haiss, and S. Gampe, "Dynamic curricular concepts for research orientated programs in optics and photonics: The importance of consistent evaluation," in *Seventeenth Conference on Education and Training in Optics and Photonics: ETOP 2023*, Optica Publishing Group, 2023, p. 1272319. doi: 10.1117/12.2670599.

[6] Y. Fujimoto, K. Wakita, and K. Suizu, "Examination optical education role of university for optical industry and efforts at Chiba Institute of Technology," in *Fifteenth Conference on Education and Training in Optics and Photonics: ETOP 2019*, Optica Publishing Group, 2019, p. 11143_114. [Online]. Available: https://opg.optica.org/abstract.cfm?URI=ETOP-2019-11143_114

[7] V. Rossi, "Simulation Led Optical Design Assessments: Emphasizing practical and computational considerations in an upper division physics lecture course," *Am J Phys*, vol. 90, pp. 279–285, Jan. 2022, doi: 10.1119/5.0064138.

[8] D. M. Vasiljevic, "Optimization of the Cooke triplet with various evolution strategies and damped least squares," in *Optical Design and Analysis Software*, R. C. Juergens, Ed., SPIE, 1999, pp. 207 – 215. doi: 10.1117/12.363779.

[9] "SMETHODS: Free courses on optical design," *aot*, vol. 2, no. 3, pp. 207–208, Jun. 2013, doi: 10.1515/aot-2013-0026.

[10] H. Parnell, "Reducing Aberrations with Ansys Zemax OpticStudio® Software," Ansys Education Resource. Accessed: Jan. 13, 2025. [Online]. Available: https://www.ansys.com/academic/educators/education-resources/reducing-aberrations-with-ansys-zemax-opticstudio-software