Simulation Led Optical Design Assessments in Upper Division Optics

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Abstract: Employing Simulation Led Optical Design Assessments in an upper division optics course provides students with a deeper understanding of optical design, interactions and devices, while reinforcing understanding of computational methods.

1. Introduction

The combined emphasis on active learning, computational and application-based approaches within the classroom has motivated the incorporation of Simulation Led Optical Design Assessments in the upper division PS 330 Optics course in the Department of Physics & Astronomy at Washburn University during the Fall 2020 semester. [1, 2] The PS 330 Optics course is a traditional lecture-based course for upper division physics majors, meeting for three 50 minute lessons each week over the course of a 15 week semester. A complete year of College or General Physics serve as prerequisites for the course. The course was taught virtually as a result of the COVID-19, however the curriculum is not dependent upon the virtual format and can be used as easily with traditional in person courses.

As a small department, upper division courses are offered on an every other year rotation, such that junior and senior physics majors enroll in the course simultaneously. Furthermore, being offered during Fall semester, the PS 330 Optics course will be among the first upper division courses taken by many of the students enrolled. A total of eight students enrolled in the PS 330 Optics course during the Fall 2020 semester: seven physics majors (three juniors, four seniors) along with a chemistry major (senior).

The PS 332 Optics Lab is taught simultaneously with the PS 330 Optics lecture course. While the lecture course need be taken as a prerequisite or concurrently with the lab course, the lab course is not directly associated with the lecture course as it is not required for majors. As such, only a subset of students enrolled in the PS 330 lecture will be enrolled simultaneously in the PS 332 lab. This eliminates the luxury of relying upon the lab course in order to supplement the lecture course with application-based optical experience. The instructor was therefore motivated to give students in the lecture course practical experience in optics, independent of the lab curriculum.

The PS 330 Optics lecture course used the 5th edition of Hecht's *Optics* as the primary resource. [3] The main topics covered in the course are wave motion, electromagnetic theory, propagation of light, geometrical optics, polarization, superposition, interference, diffraction, Fourier optics and holography. The instructor specializes in biomedical imaging, holographic microscopy and Fourier optics, so the instructor supplemented the later portion of the curriculum with additional materials specific to those fields.

In order to build application-based experience into the PS 330 Optics curriculum, three Simulation Led Optical Design Assessments were adopted in course. The first two of these assessments were implemented as projects in-lieu of weekly problem solving homework assignments from the text. In order to reflect the emphasis on this approach to the later portion of the course, the final exam also employed the same format.

2. Preliminary Activities

Computer modeling and simulations using *GNU Octave* were incorporated throughout the course in order to promote active learning and student interactions in the course (Fig. 1). Beyond providing improved visualization of advanced topics, these computer models and simulations also served to introduce many students to computational methods and applications—a good number of students in the course will have little to no computational experience prior to enrolling in the course. Even those students with computational experience were generally not familiar with computational aspects particular to modeling optical and imaging applications, so it was essential that computational modeling and simulations be incorporated into the curriculum early and frequently in order to give students the skills necessary to complete the simulation aspects of the assessments presented here.

These activities started by simply having students adapt parameters in existing code in order to demonstrate the physical dependencies of the phenomena upon those parameters, such as varying the signs of the spatial and temporal terms in a wave function in order to see the effect on the wave's direction of travel. Students would later

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go on to further adapt code from later simulations in order to generate a desired result, such as representing a given function via a Fourier series. Students would also write their own code, such as when modeling diffraction. Beyond one-dimensional applications, these activities also introduced students to coding for 2D applications, such as Fourier Optics, spatial filtering and 2D convolutions.

Students worked through computer activities in pairs, while the instructor monitored student progress and was available for questions. Although students worked through the computational activities in pairs, they were each responsible for writing up graded independent summaries of each activity. This way, while students were able to learn together, they were required to demonstrate their understanding of the material independently.

Activity/Topic	Computational Considerations						
	vectors and arrays	logical flow	conditionals	Fourier analysis (fft & ifft)	complex variables	2D Fourier analysis (fft2, ifft2)	convolution
Waves Tutorial	x	x					
Electric Dipole	x	x					
Superposition Same Frequency	x	x	x				
Superposition Different Frequency	x	x	x				
Diffraction Grating	x						
FFT Tutorial	x	x		x			
Fourier Optics	x		x		x	x	x
Autocorrelation	x	x	x		x	x	x
Optical Simulation of a Digital Fourier Holographic Microscope	x		x		x	x	x

Fig. 1. Topics covered via preliminary computational activities and the associated considerations.

3. Simulation Led Optical Design Assesements

For the final in class computational activity (Optical Simulation of a Digital Fourier Holographic Microscope), students were provided with an example simulation of an entire optical device and the corresponding optical design schematic (Fig. 2). This final in class activity served as a working model of the methods and expectations for the simulation led optical design assessments.

Students were then assigned two simulation led optical design assessments for homework, followed by a third simulation led optical design assessment as their final exam (Fig. 3). The second simulation led optical design assessment (Digital Holographic Microscopy) built off of the previous assessment (Fourier Optics) and was closely related to the Optical Simulation of a Digital Fourier Holographic Microscope example provided as the final in class activity. This way, the simulation led optical design assessments were built with scaffolding intentionally incorporated within them.

For each assessment, students were instructed to create a schematic of the optical design of the system. Furthermore, students were also required to simulate how each sequential element of the device operates on the field and to describe those operations in their write up (Fig. 4). To do this, students first had to simulate a sample.

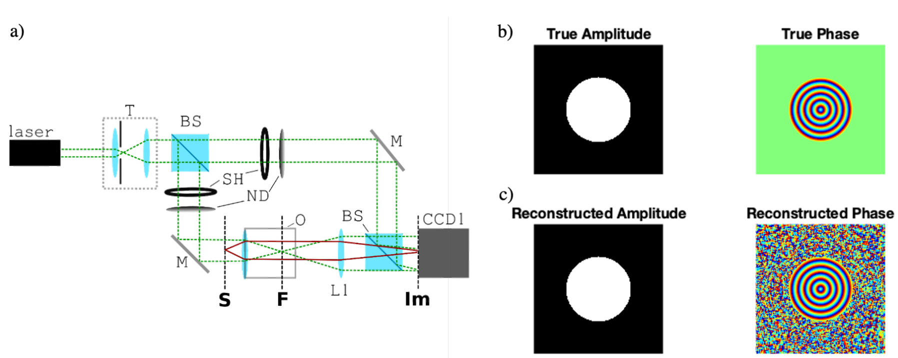

Fig. 2. a) The optical design and corresponding b) sample and c) reconstructed amplitude and phase provided to students as a demonstration of the Optical Simulation of a Digital Fourier Holographic Microscope.

Assignment Name	Assessment Type	Optical Considerations		Computational Considerations	
Fourier Optics	Homework	dark-field imaging	lens diagrams	vectors & arrays	complex variables
		spatial filtering	camera specifications	logical flow	2D Fourier analysis (fft2 & ifft2)
		Fourier Imaging		conditionals	spatial filtering
Digital Holographic Microscopy	Homework	Fourier optics	phase imaging	vectors & arrays	2D Fourier analysis (fft2 & ifft2)
		holography	lens diagrams	logical flow	convolution
		superposition	camera specifications	conditionals	wrapped images
		off-axis holography		complex variables	
Polarized Imaging Microscope	Exam	polarization	specular reflection	vectors & arrays	2D Fourier analysis (fft2 & ifft2)
		polarization via reflection	Fresnel equations	logical flow	convolution
		reflectance microscopy	lens diagrams	conditionals	
		magnification	camera specifications	complex variables	

Fig. 3. A breakdown of content covered in the simulation led optical design assessments.

Practical Homework 1: Fourier Optics

INTRODUCTION: Darkfield microscopy is a means of using a cone of illumination in order to image an object, such that any directly transmitted (unscattered) light is not collected by the objective. Therefore, only light that is scattered by the sample has a possibility of being deflected towards and therefore collected by the objective. See the Nikon MicroscopyU Darkfield Illumination article for a more detailed descriptoin of darkfiled imaging. As a result of darkfield imaging, the background light (what we would in Fourier Optics refer to as the DC signal) is removed from the image. As an alternative to using a cone of illumination followed by a regular microscope, darkfield imaging can also be achieved via the application of Fourier methods to samples under normal (planar) illumination.

TASKS:

1. Design a Fourier Microscope that can be used for darkfield imaging. Do not design a darkfield microscope.
2. Write a computer simulation in order to model your system from step 1, demonstrating how it operates. When modeling an optical system, all optical operations carried out by optical components need to be included as individual processes within the simulation.

WRITE UP:

1. Please include a diagram/schematic of your imaging system with each element labeled. Also, include a brief description of how the system as a whole works along with details of how each optical element functions/acts on the field.
2. Please upload your code, as well as your results—give a figure for each major operation along with a description. Your figures and descriptions should be in a single document.

Fig. 4. Instructions given to students for a Simulation Led Optical Design Assessment.

As with the preliminary activities, students again worked in pairs on their assessments but were responsible for their own graded, independent write up.

4. Conclusion

Simulation Led Optical Design Assessments were well received by students in their upper division optics course. Furthermore, these assessments had the benefit of providing application-based experience to students in a lecture course that had no required optical lab component. Beyond providing students with a deeper understanding of optical design, interactions and devices, these assessments also reinforced student understanding of computational methods.

References

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3. E. Hecht, *Optics*, 5th ed. (Pearson, 2017).