Two to the Sixth and Counting: A Lifetime of Optical Experiences

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Abstract

This presentation will cover 64 years of experience with telescopes, optical components, optical coatings, large optics, optical fabrication, lasers and related subjects. It will focus on five topic areas paying special attention to critical lessons learned in these areas. Part 1 will cover contributions and inherent value of mentoring in optical and astronomical sciences. This will include specific personal experiences and valuable lessons learned from teachers and mentors going back to the beginning of the space age and the first satellites. It will also cover selected examples from the author's mentoring and community optics and astronomy outreach efforts. Part 2 will delineate the lessons learned from the investigation and independent expert review and assessment of optical damage incidents over a period of five decades. It will also recount frequent optical misconceptions that have negatively impacted efficient system development and implementation over the years and how to avoid them. Part 3 will consist of a short tutorial on the tools, techniques, and the "how and why" of optical inspection. This will be interlinked with the previous optical damage and mistakes topic, where possible. Part 4 will consist of the author's involvement and experiences in optical education with emphasis on the founding and early years of the University of Arizona Optical Sciences Center, now the College of Optical Sciences. Part 5 will cover the enduring issues and challenges for managers, planners and contributing scientists for large optics and telescope projects. This brief overview will follow up and expand upon the author's presentation on this topic at the 1985 "*SPIE Optical Fabrication and Testing Workshop: Large Telescope Optics",* Albuquerque, NM. Throughout all topic areas presented, the author will stress the lessons learned and the value of these lessons to the planning, management and successful execution of future optics projects and programs.

Transcription

This talk covers about sixty four years of work on numerous optical adventures (Fig. 1 – Original Fig.**1**) I've had. I ended up putting together about five-hundred charts for this talk and then cut it back down to about two hundred, realizing that even though the dry runs seem to take a little over an hour, today I may think of something along the way that you should know about. Be that as it may, I think we will have enough time to complete this "mini" 5-Topic version (Fig. 2 – Original Figs **3-7**)), though I will probably only pay lip service to the last couple of topics to be presented here. I think the first three (20-minutes-each) topics are the most interesting, although the fourth topic is on how the University of Arizona's Optical Sciences Center was born (the dedications and groundbreaking were completed by nineteen-sixty-seven and my career extends back to then) and some of you are likely to find it, as well as the fifth topic on future possibilities to be of interest as well.

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In the past I've given many talks on the history of optical telescopes and associated aspects of astronomy and space and also on optical design, fabrication & testing. Also, I've spent a lot of time, literally thousands of hours, coating big optics and little optics and high power laser resonator optics so I got quite a bit of material to go through today. Most of this paper is more like a picture show punctuated here and there by a narrative that ties to key lessons learned. I have about seventy five thousand photos and slides, and have boiled this all down to ~145, though many are montages. Anyway, please bear with me; I think it will be interesting.

I know optics has a fascination for me - it has all my life, and, as you listen today, I hope that you will be able to share in the enjoyment. Please note that these recollections, interviews and opinions are all my own. I don't represent the Air Force or even my own company, Tau Technologies (now up to about 25 folk) in this work. It is important to note that I'm trying to stay completely away from anything that is remotely classified, I'm trying equally hard to stay away from anything which is certainly company proprietary or sensitive. I believe I have succeeded in doing this

When I was younger I had interest in archaeology & history, and, over the years, I've always tried to pursue my archaeology goals when I could. I had a full four-year scholarship at the University of Chicago and was going to head towards a major in Egyptology but turned it down to become a space guy when Sputnik got launched. Therefore, the backdrop for a number of my slides is archeological, with a (stretched at times) tie-in to the subject at hand. Some of my initial work was watching satellite passes using the Baker-Nunn System, and I consider Jim Baker to be one of the finest men I've ever met. I learned from him, and that immediately brings up the first broad topic of mentoring as an important Lesson Learned. I try to mentor in many ways, through outreach groups and science fairs and the Women In Astronomy and Sciences Group, to working with female astronauts, and now around the country though various presentations. I'm happy to do this and probably should write a book on the subject (maybe this is the start).I doubt if any of us would be where we are today without a mentor.

I've always been a closet astronomer and archaeologist, although I'm really an optical physicist, sort of, anyway. [A picture, Original #5, is shown of 5 sphinxes, all with eyeglasses superimposed on each.] OK, here's a quiz - which of these sphinxes are uncannily good optical inspectors? [Two pairs of the right-most sphinxes have eyeglasses with a rosy-hue.] The answer is that the 3 on the left are the best inspectors. You can't be a good inspector if you see the world through rose-colored glasses. I've been doing optical inspection for fifty five or sixty years and I can't even begin to say how many hundreds if not thousands of hours I've spent in inspection. Over the years we see the importance of the Lesson to not report something to be true when the values being reported are not supported by hard data.

Let's spend a little longer on Mentoring (Fig 3 – a selection of Seven Original Figures From **9** through **29**). Mentor is a two-way street. if you're going to mentor you have to want to mentor, and if you're going to be mentored you have to want to be mentored. [What follows here is a discussion of several of the people some must had never heard of, that were so important in Jim's life.] You should all think about whom you can mentor what you can do to develop skills in others. The "word" mentor goes back to about twelve-hundred BCE to Homer. Mentor was the name of Telemachus' (Odeysseus' son) trusted advisor. Homer

wrote his material in ~ the eighth century BCE, but the time period he covered was back several hundred years earlier. Please think about who your mentors were. Think about what you owe them, and what they've done for you. Your co-workers can be mentors to you, and you can be a mentor to them, be it technical, or career-path related. Lots of your colleagues may have their own “I love me walls”. They are likely there for a reason. Listen & learn.

OK, let’s switch gears from Mentoring to Mistakes (Fig’s. 4, 5, & 6 – Original Figures **31** & **32, 33** – **37** & **39** – **42,** and **44**-**49**, respectively). Over the years I really got interested in seeing how things got messed up in optics. Optical errors have been recorded starting in 2,600 BCE [Editor’s note: several examples provided], and you’d be surprised to see how many “optical” people still miss something basic. They may think a Ritchey-Chretien corrects field-curvature or any of hundreds of examples, where assumptions/presumptions are not firmly grounded. Of course one of the main ones is that the glass is friable – it breaks (even membrane mirrors can be sensitive to pin-holes, and, in glass, drill stops don’t always stop runaway cracks). And it the glass is coated, the costs to make a repair can further escalate, sometimes substantially. Handling/packaging and monitoring during transit (sometimes in the rain) can each be a critical step There is a very broad variety of things that can go wrong, from moving precious materials and being stopped by guards, to pilfered optics, to mold and vermin/bug/moth infestations, to choosing the correct epoxies (including thicknesses, material properties over worst-case temperature and humidity ranges) and assembly fixturing methods, to controlling contaminants/pollens, to dropping wrenches but having them “fall-up” (an important lesson here is to “always” wear lanyards when working with tools near exposed optical parts). [Editor’s note: If you’re working with HEL optics, just the stray light can be a substantial health hazard unless it is controlled and people are adequately protected. There can also be important interactions with contaminants/particulates to contend with, so use witness sample to help you assess things when needed, though if you can successfully measure actual parts, so much the better.] Also, remember, large optics can exert substantial forces if they are moving or spinning – don’t have an accident where someone gets hurt; set controls and train folk to avoid what can be dire consequences, be it in handling optics, climbing ladders, or working on platforms or in elevated stations!

There are lots of different Lessons. One is that not everyone will see your work from the same perspective. In the top left of Figure 7 (Original Figures **50**, **61**, **69**, **71**, **74**, & **75**), the nice telescope and photographic work showed excess clutter on the floor and the result was a briefing that wound up less positive than expected. Also, be aware that fires do happen. I’ve been through one and lost nearly everything. If you’re the site manager, look around and be sure you and your crew/hardware will be safe. [Editor’s note: the same holds for working with Cryogens.] Liklewise, pre-plan situations where one might need to stand on or handle cold objects for extended periods of time or inadvertently stare at the sun.] Also shown in the figure is the destruction of a Cervit mirror from plunge coring – where this could generally be from using a dull tool, to the use of the wrong abrasives, to using inappropriate speeds/ & feeds. The oyster chpping shown came about from dropping a large boxed mirror “cushioned” by peanuts, where the peanuts had shifted during handling. Don’t rely on chance when you are securing your optics. Also, if you’re using acids to clean concave mirrors be careful; chemical burns are far from pleasant, and recognize that if protective coating layers – e.g. enhanced silver - get breached., further coating damage can happen.

OK, at this point let's turn our attention to inspection (see Figure 8 – Original Fig's. **82**, **83**, **85**, **86**, and **112**). There are three critical considerations in inspection - the first one is illumination, the second one illumination, and the third one is, guess what, illumination! Critical items include details on how you do your inspection – what wavelength/bandpass/ spectral properties are involved, what polarizations are going to be used, will beams be convergent or divergent, and will parts be viewed from multiple angles, e.g. from the back or side? How small an imperfection (pinhole, bubble, void, crazing, tooling marks, imperfection, etc.) do you need to see? How do you know how good your test is? Also, you can miss a lot if your illumination isn't correct and your room isn't dark (and sometimes your parts may be visibly opaque). (It's not uncommon to have a suite of different flashlights to use on different Projects.) It's not always easy to distinguish a scratch from a fracture, and this is often very important. If you're not sure what to do on some aspect of inspection, take a course, &/or get help from an expert. There are lots of tools you can use in inspection, and the vendors of these instruments can be a good source of information.

Switching gears yet again, we offer a few brief comments on the birth of the Optical Sciences Center at the University of Arizona (see Figure 9 – Original Figures **128**, **132**, & **133**). I was an AF Captain back then (1968) and I was OSC's first graduate Though it's not heavily recognized, twelve of the first forty-two OSC graduates were AF Officers. [Editor's note: One Lesson here might be to grow your own staff when a need is recognized that can't be filled in other ways.]

Lastly we talk briefly about some of the challenges that continue today that relate to large optics fabrication (SEE Figure 10 – Original Fig's **134**, **135**, **137**, and **142**). I discussed this in an SPIE Paper back in 1985 and I thought a few comments on this subject would be fitting – what was said then that was wrong, what was right, and grade how well our community seems to be doing in this area.. Major progress continues on weight reduction. Also, the industry is getting a little better at writing Specifications.

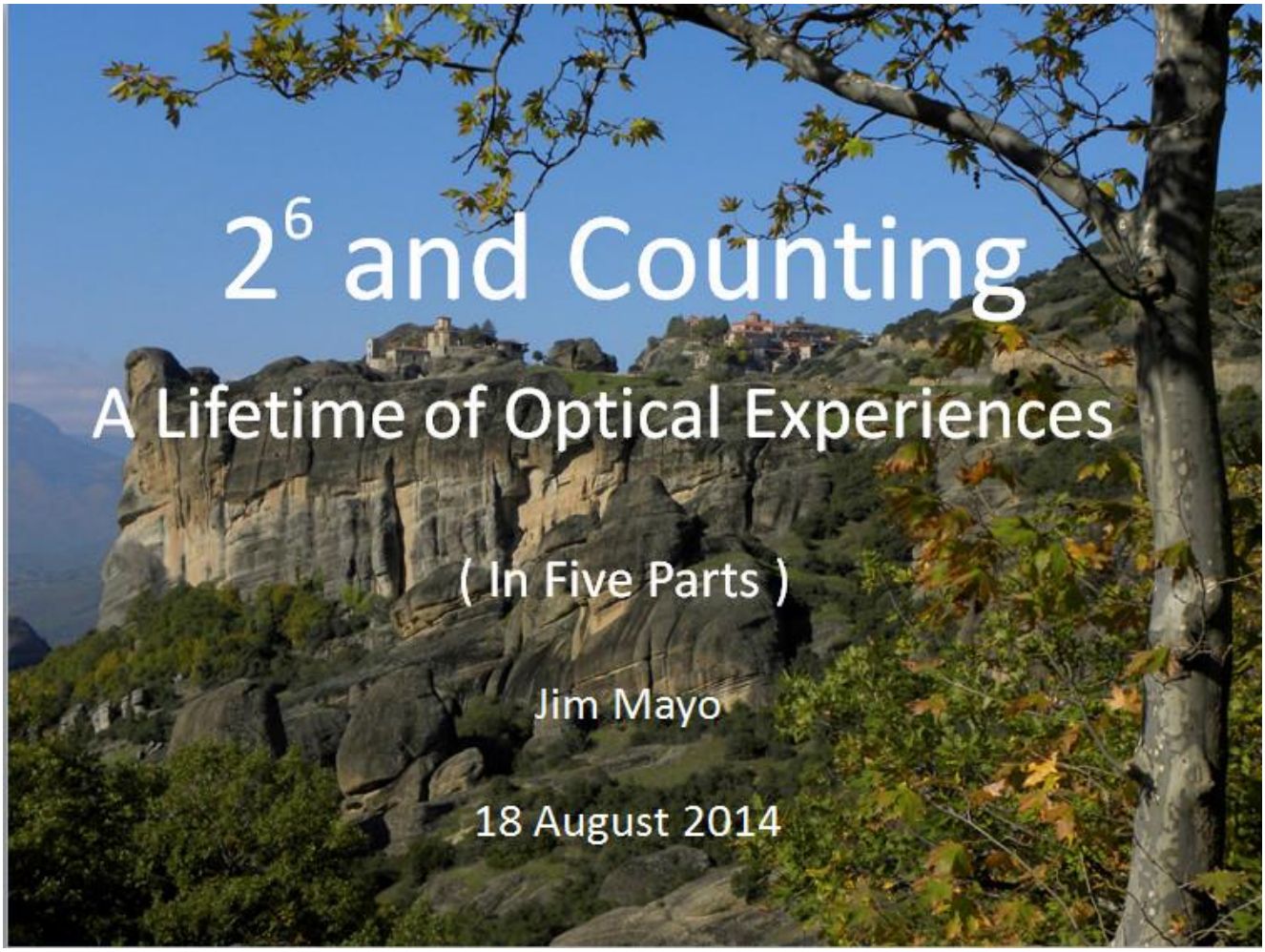

2^6 and Counting
A Lifetime of Optical Experiences
(In Five Parts)
Jim Mayo
18 August 2014

Figure 1

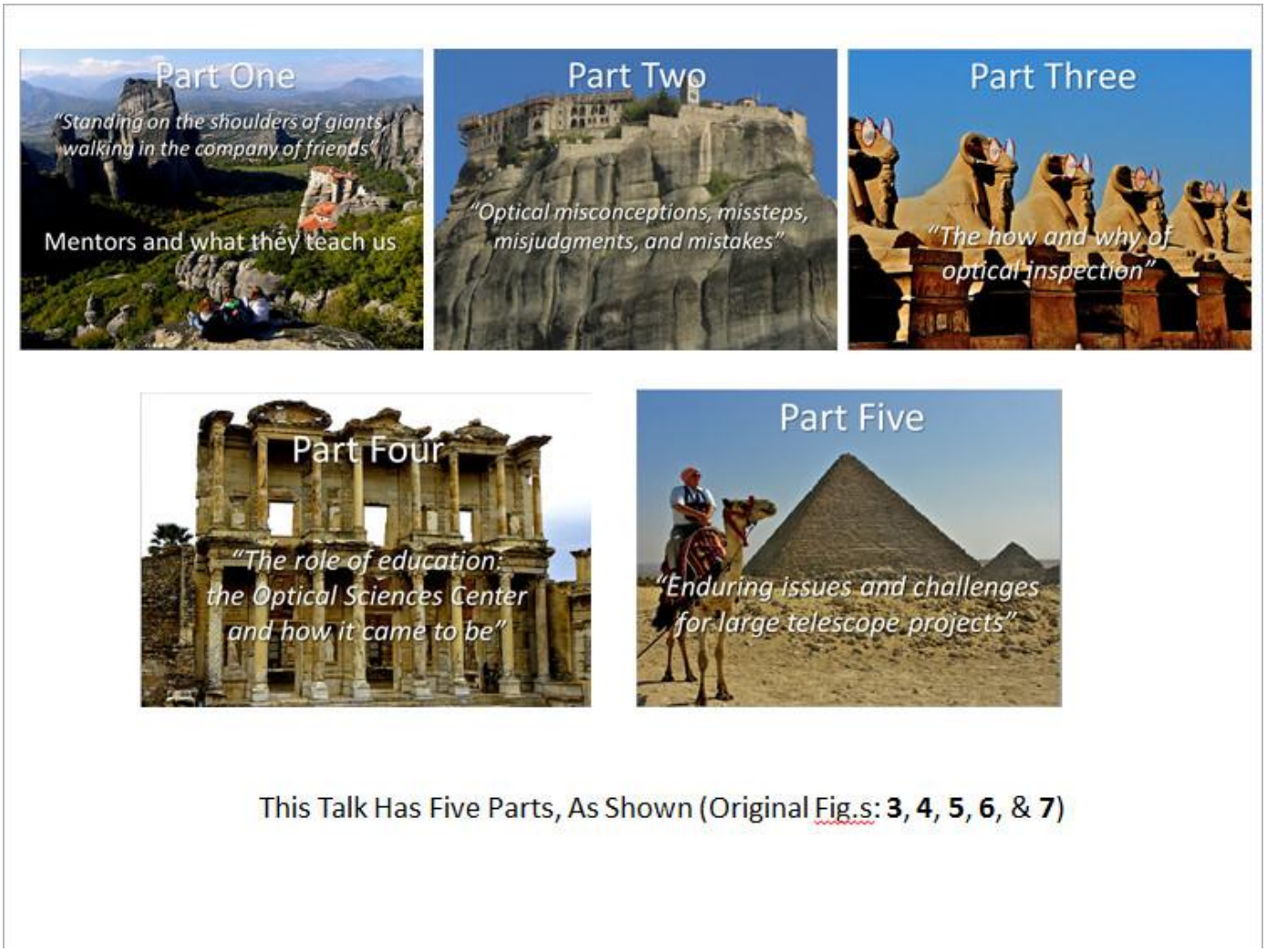

Part One
"Standing on the shoulders of giants, walking in the company of friends"
Mentors and what they teach us
Part Two
"Optical misconceptions, missteps, misjudgments, and mistakes"
Part Three
"The how and why of optical inspection"
Part Four
"The role of education: the Optical Sciences Center and how it came to be"
Part Five
"Enduring issues and challenges for large telescope projects"
This Talk Has Five Parts, As Shown (Original Fig.s: 3, 4, 5, 6, & 7)

Figure 2

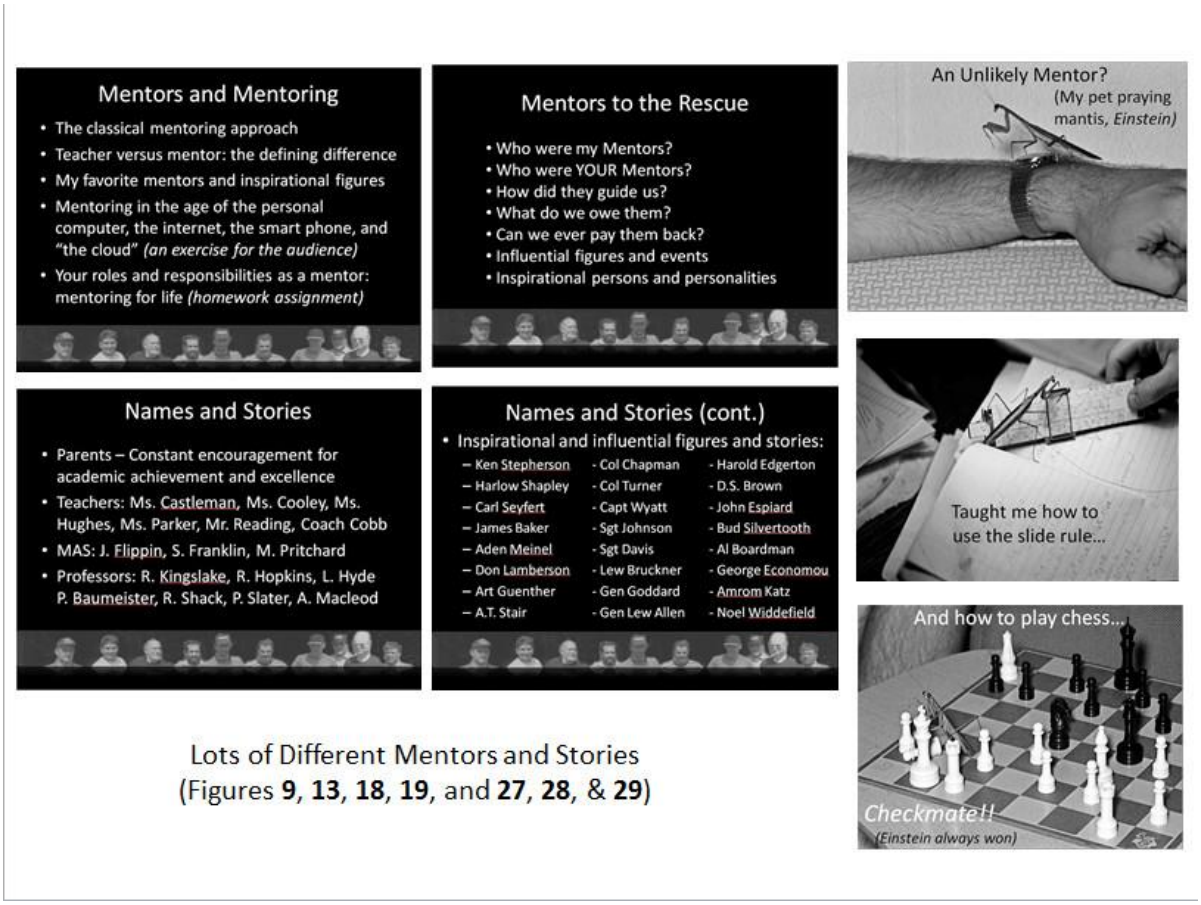


Figure 3

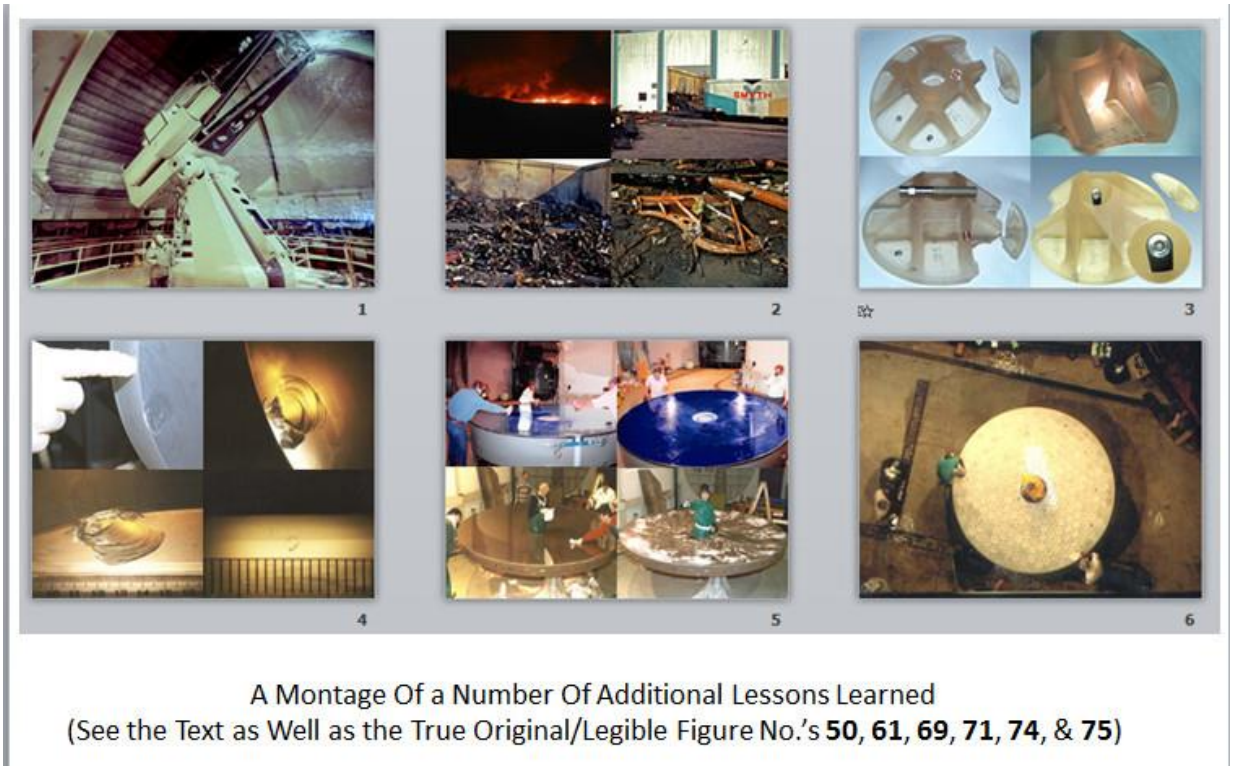
Figure 4

Evocative Montage Of Some Early Lessons Learned (True Orig./Legible Fig. No.'s **33-37** & **39-42**)

Figure 5

Another Evocative Montage Of a Great Many Lessons Learned Over the Years
(See the Text as Well as the True Original/Legible Figure No.'s **44 - 49**)

Figure 6



A Montage Of a Number Of Additional Lessons Learned
(See the Text as Well as the True Original/Legible Figure No.'s **50**, **61**, **69**, **71**, **74**, & **75**)

Figure 7

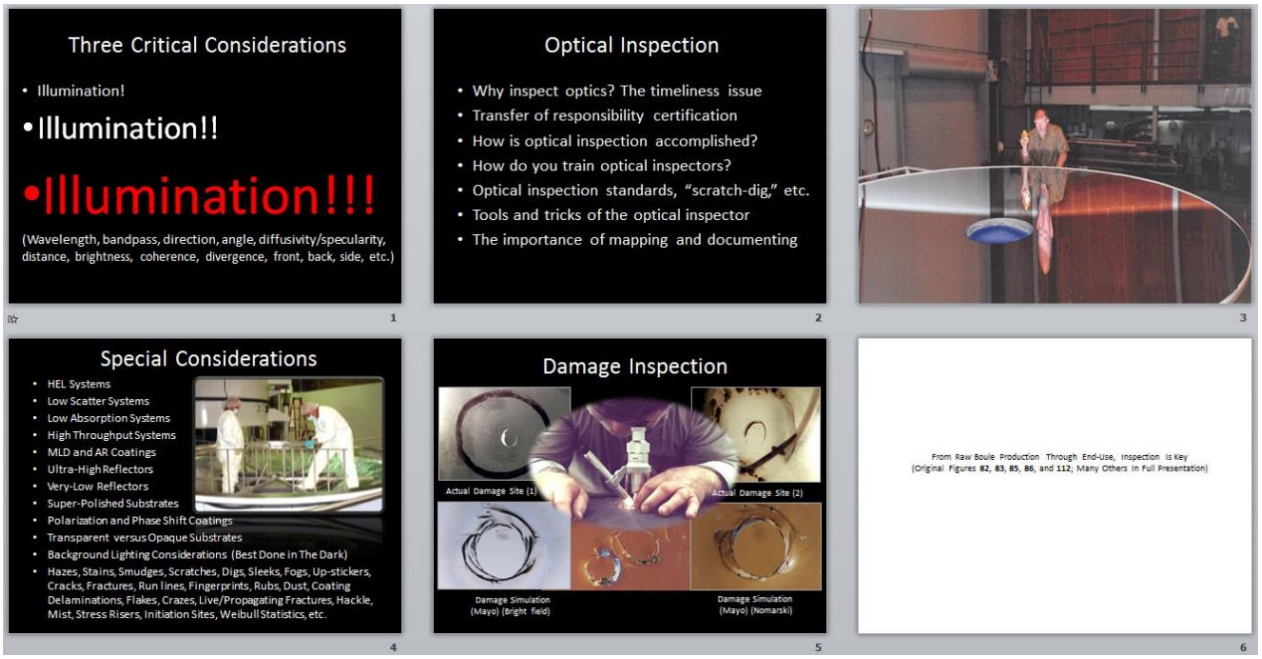
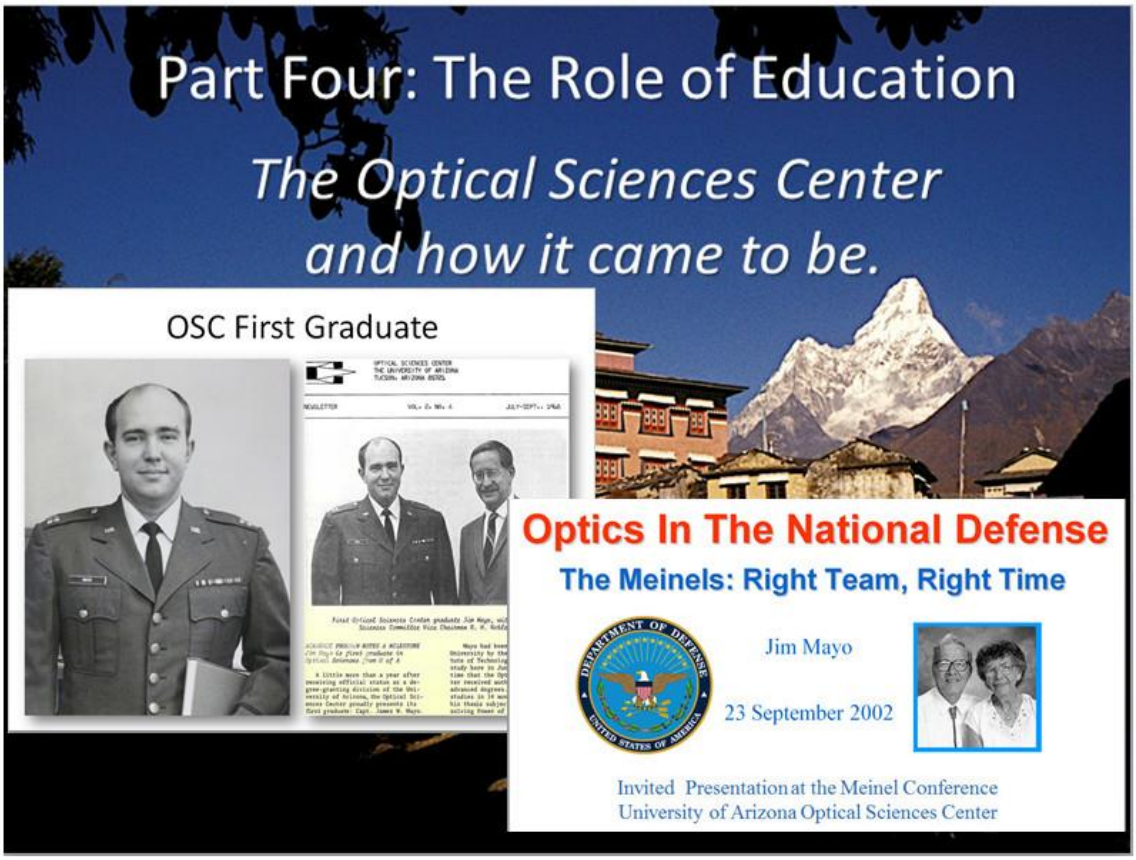
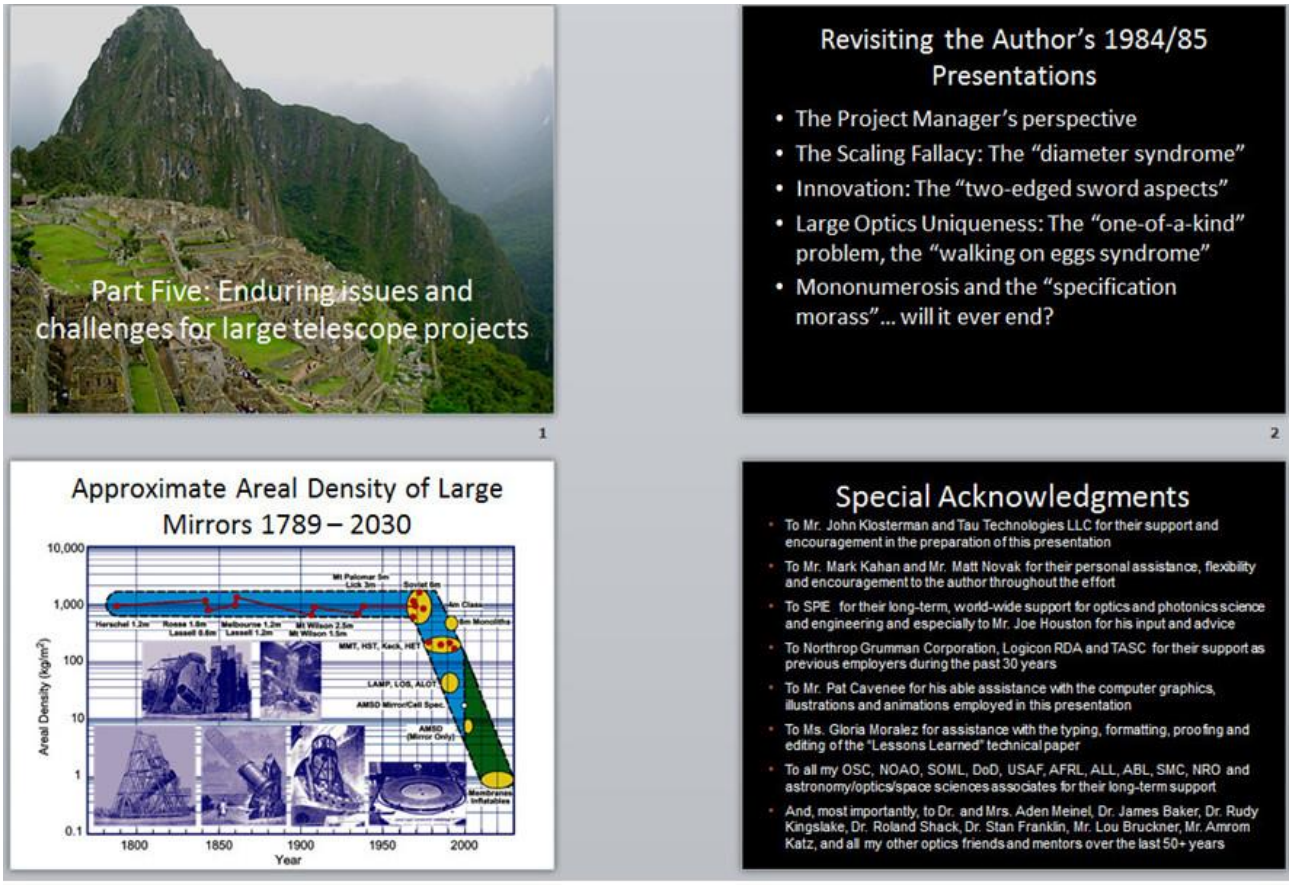


Figure 8



The Importance Of Education Can't Be Understated (See Original Fig. No's **128**, **132**, & **133**)

Figure 9



There Are Always New Lessons To Learn

(Editor's Note: The Original Article Includes Many References & Credits. No Slight Intended In This Necessary Edit Based On Space Constraints. Please See the Full/Original Paper For These (Orig. Fig. No's **134**, **135**, **137**, & **142**)

Figure 10

[Please Note: This Keynote Presentation has an SPIE approved somewhat modified format as it is a transcript from a video we made of Jim Mayo's excellent talk. It has been edited here and there by tile Session Chair to better fit this archival/written format, and the Chair apologizes to both the author and the reader for any inadvertent transcription errors. The original text includes 145 figures (102 MBs without the audio); and the bolded numbers in the text and Figures are used to refer to which of the Original selected but still sequential figures the Session Chair chose to abstract and include in this specific Volume. There is a lot of wonderful personal material that is in the video which has been edited out here as it fits the video format best, but it, and all the Figures have high value. Therefore, the interested reader is encouraged to view the full one-hour and twenty-minute video recording of this talk, which also includes all the Figures. It is scheduled to be available as an SPIE download. MK-]