Creating Rewarding Careers in Industrial Physics and Physics Education

San Diego State University
Physics Colloquium

October 4, 2019

Dr. Larry Woolf
General Atomics Aeronautical Systems, Inc.
General Atomics Sciences Education Foundation
www.ga-asi.com
www.sci-ed-ga.org
Outline

- Part 1: Career in industry
- Part 2: Education path
- Part 3: Preparing students for careers – Phys21

Limited highlights reel

- What does an industrial physicist do?
- Can you get involved in physics education in industry?
- What is the best way to prepare undergraduate physics students for careers?
- How are these questions related?
Part 1: My career in 4 snapshots

- PhD UCSD, Low temperature heat capacity of magnetic superconductors, Prof. Brian Maple 1980
- Post-doc at Exxon Research, 1980-1982
- Hired as solid state physicist at General Atomics (GA) in 1982 to help develop non-nuclear programs. At GA for 37 years – mostly materials R&D

Every story and perspective of life in industry is unique and changes depending on the stage of one’s career
Graphite and intercalated graphite fibers—potential lightweight electrical conductors

Used graduate school knowledge to set up low temperature high H lab to measure magnetoresistance
Model thermophotovoltaic energy conversion systems and test cells – space nuclear power

High temperature materials + optical properties →
HTS discovered: Led high temperature superconducting (HTS) wire development project

Graduate school + ceramic materials + thick film coatings →

- 7 years, papers, patents, presentations
- Effort was commercially unsuccessful
- Motivated education activities

Fig. 4. Polished transverse cross section of an as-coated silver and superconductor coated silver tape.

Fig. 5. Polished transverse cross section of a fully processed silver and superconductor coated silver tape.

Fabrication of Long Length Bi-2223 Superconductor Tape Using Continuous Electrophoretic Deposition on Round and Flat Substrates

J. D. WOOLF, T. L. FIGUEROA, R. A. OLSTAD, F. E. ELGNER, and T. OHIKAWA

Pacific Superconductors Division, General Atomics, San Diego, CA 92186
Initially great story of black cool paint ~2008

Thin film coatings + optical properties

95603. Automotive Coating Reflectivity Standards. (Draft regulation for 2012-2016)
(a) The opaque surfaces of new passenger cars, light-duty trucks, and medium duty vehicles less than or equal to 10,000 pounds must reflect at least 20 percent of the impinging direct solar energy.
Cool paints have high near-IR reflectance (700-2500nm) to reduce solar heating.
Use of optical properties of Si to make a cool coating

Differences in $n$: reflection
$k$: absorption
Finally sad story of black cool paint


Based on input from the automotive industry, paint, pigment suppliers, and comments from a public workshop held on March 12th [2009], ARB staff has determined that a clear path to achieve the levels of solar reflectivity for the darker colors has not yet been identified. Now we’re challenging inventors to create paint in all colors to reflect heat from the sun. Yes, even black paint.

Stanley Young
California Air Resources Board
Evolution of job responsibilities over time
Advantages of Careers in Industry

• Goal is development of a product
• Satisfaction of seeing your efforts make a difference to people
• Opportunities for patents, business development
• Challenge of not just doing science, but applying science to technology, then figuring out how to commercialize it in dynamic marketplace
• Challenge of learning how to perform R&D and scale-up under schedule, cost, equipment, quality, personnel, facilities constraints
• Varied career opportunities: science, technology, manufacturing, program management, group management, quality
• Many different projects; constant learning needed
• Pay, bonus pool, stock options
Disadvantages of Careers in Industry

- Often minimal publications/presentations and interactions with peers due to proprietary, export controls, security issues
- Reduced likelihood of being recognized for your achievements from an academic perspective, e.g. awards, fellowships
- Focus on a defined goal (NOT curiosity driven)
- Limited freedom to pursue your personal interests
- (Almost) No sabbaticals, no tenure
- Need to rapidly reinvent yourself as technologies and business areas change
My 15 Point Guide to Success

1. Be responsive – return phone calls and emails promptly. When asked to do something, do it on time – be sure to ask when it should be done. Document requests and responses in writing.

2. Become the world expert in your particular area.

3. Continually expand the depth and breadth of your knowledge and skills.

4. Utilize all information resources available - books, science magazines, web sites, search engines, search services, colleagues, patents, trade magazines, catalogs, sales reps, conferences.

5. Get involved with or develop projects that have a high probability of contributing to the company’s success.
My 15 Point Guide to Success

6. Understand and be aware of project constraints such as your personnel and company capabilities, competitor’s strengths, and customer needs.

7. Innovate continuously. Always push your envelope as well as the science and technology envelope. Stay uncomfortable with what your skills and knowledge are.

8. Document your work in manner that is actionable and can be easily understood by a co-worker a year from now. Use spreadsheets, tables and charts to convey your results in a concise, visual, and easy-to-understand manner.

9. Make sure that you learn something useful from any tests or experiments that you perform. These results should form the basis for future tests.

10. Learn from your mistakes. Don’t repeat them.

Remember 8 when I discuss the Phys21 Supplement
My 15 Point Guide to Success

11. Don’t believe everything you are told, even if it is company lore or told to you by an expert. Be skeptical.

12. Enjoy your work.

13. Treat everyone you work with (above and below you) with respect. Thank them for their work. Acknowledge their contributions whenever possible. Keep them informed as to what you are doing and why you are doing it.

14. Have a sense of humor.

15. Develop a unique and necessary skill and knowledge set that complements those of your co-workers and greatly increases the value of your project/team. Be indispensable.
Part 2: Education activities are possible in industry

- Outreach program started at GA in 1992
- Many companies have education outreach programs
- Details and funding are highly dependent on the company, management support, and the initiative and desire of the individual scientist

Why was I motivated to get involved and then more involved?

- Opportunities arose
- 7 year unsuccessful effort to develop high Tc superconducting wire
1993-2001: Education modules, posters, presentations, reviews
“The journey of a thousand miles begins with one step” Lao Tzu

- 1993: Co-author: An Exploration of Materials Science Module; workshops
- 1996: Author: The Line of Resistance Module; presentations
- 1996: Author: Seeing the Light: Physics and Materials Science of Incandescent Light Bulb Module; presentations
- 1997: APS Teacher Scientist Alliance 5 day workshop K-6 science
- 1997: Author: It’s a Colorful Life Module; workshops
- 1997: GA Sciences Education Foundation web site
- 1997: Reviewer for NSF Instructional Materials Development panel
- 1998: Reviewer for LHS FOSS Electronics middle school unit
- 1998: Testified about state science standards to CA State Board of Education
- 1999: Presented 4 workshops at NSF sponsored workshop in U Wisconsin
- 1999: Wrote and managed science education petition to improve state science education:
- 2001: Presented 3 4-hour workshops at AAPT winter meeting in San Diego
- 1999-2004: Color, Light, Seasons posters
- 2001: Presented workshop at High School Teachers Day April APS
2002-Present: NSF/APS National Panels, FEd chair, Foundation president

- 2002: LHS FOSS middle school unit on Force and Motion – design/review
- 2002: Chair – COV Review Panel for NSF IMD program
- 2003-2008: Reviewer for BSCS inquiry based high school science curriculum
- 2004: Testified to CA state board of education on draft criteria for K-8
- 2004: NSF site review of GEMS Seeds of Science/Roots of Reading – LHS
- 2005: Chair: review of Nat. Center for Learning/Teaching in Nanoscale S/E
- 2007: Site review of SRI Nanosense program for NSF
- 2007: President/Chair GA Sciences Education Foundation
- 2007: Steering committee: NSF Materials Education Workshop
- 2008: Elected to chair line, APS Forum on Education
- 2010: Org. committee: 2nd workshop on graduate education in physics
- 2010: APS Committee on Education
- 2012: NSF review panel for Cornell High Energy Synchrotron Source
- 2014: NSF review panel for National High Magnetic Field Laboratory
- 2014: APS/AAPT Joint Task Force on Undergraduate Physics Programs-Phys21
- 2016: APS Development Advisory Committee
- 2016: APS Best Practices for Undergraduate Physics Programs (EP3)
- 2019: APS Excellence in Physics Education Award selection committee
Moral

- Stay open to opportunities
- Never say no (some of my peers disagree!)
- Do what you say you will do
- Do a good job
- If motivated/annoyed, then create/solve
- Utilize your unique skills and knowledge

Let’s look at visual curriculum – posters
  - Multiple representations
  - Relationships
  - Context
Color mixing

Confusion about primary colors and poor model – same for light and pigment

The result of mixing light colors together.
- White is the result of superimposing the three beams of light, green, red, and blue, the primary light colors.
- The projection of two of these colors produces the secondary light colors: yellow (the result of superimposing green and red), magenta (the result of superimposing red and intense blue) and cyan blue (the result of superimposing intense blue and green).

The result of mixing pigment colors together.
- Black is the result of superimposing the three primary colors: yellow, red, and blue.
- Mixing yellow and red together produces vermilion.
- Red plus blue gives us violet.
- By combining blue with yellow we get green.

Barron’s Art Handbooks: Mixing Colors 1. Watercolor
Publicity for the correct color wheels ...
Still … Water misconceptions … by experts!

A professor of oceanography documented 110 misconceptions about the oceans held by his students who were not science majors. In this article, we’ve focused on a smaller number of misconceptions that might be held by elementary students. In addition, we’ve included ideas for formative assessment and suggestions for teaching correct scientific concepts and principles.

## MISCONCEPTIONS

### Ocean Characteristics

<table>
<thead>
<tr>
<th>STUDENTS MAY THINK...</th>
<th>INSTEAD OF THINKING...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oceans are shaped like a bowl.</td>
<td>While the continental shelf and continental slope may remind students of a bowl, the ocean floor is not flat, nor is it uniform. Canyons, mountains, and plains are all found on the sea floor.</td>
</tr>
<tr>
<td>Oceans are deepest in the middle.</td>
<td>Many of the oceans’ deepest points are trenches, deep canyons that are formed at plate boundaries. These are not in the middle of oceans.</td>
</tr>
<tr>
<td>The sea floor is flat.</td>
<td>The sea floor has canyons, mountains and mountain ranges, and plains just as the land does. Many of these features are much larger than those found on land.</td>
</tr>
<tr>
<td>The bottom of the ocean is a big, sandy desert.</td>
<td>The ocean floor is rocky and uneven.</td>
</tr>
<tr>
<td>Coasts and coastlines do not change.</td>
<td>Coasts and coastlines change as a result of erosion. Sea-level rise may also affect them.</td>
</tr>
<tr>
<td>The ocean is blue because it reflects the color of the sky.</td>
<td>Sunlight is made up of all colors of the rainbow. When sunlight hits the ocean it is scattered by the water molecules. Blue light is scattered the most – which is why the ocean looks blue. However, floating plants, sediments, and algae may make the ocean appear to be green, yellow, or even red!</td>
</tr>
</tbody>
</table>

[https://beyondpenguins.ehe.osu.edu/issue/polar-oceans/common-misconceptions-about-oceans#misconceptions](https://beyondpenguins.ehe.osu.edu/issue/polar-oceans/common-misconceptions-about-oceans#misconceptions)
Blue water confusion: Light Matters Poster

Light Matters

- Light is not colored. Color is a human visual response that depends on the spectrum of visible light entering our eyes—the color we observe then depends on the reponsivity of the long, middle, and short wavelength sensitive cones in our eyes and the processing of these signals by the brain.
- The color of an object seen by reflected light depends on both the light spectrum illuminating the object as well as the reflectance spectrum of the object. This is why the color of clothes changes with illumination conditions.
- Light of a single wavelength corresponds to a definite perceived color. Most perceived colors can be evoked by a large number of different light spectra entering our eyes.
- For further details about and limitations of the explanations given in this poster, consult the references.

Light Emission

Wavelength (nm)
Infrared Light
Visible Light
Ultraviolet Light
Simplified Model of Visible Light Spectrum Used in this Poster

Objects emit light over a wide continuous range of wavelengths. At each temperature, this range can be approximated by three separated wavelengths. The rates for additive color mixing can then be used to predict how the color of hot objects changes with increasing temperature.

In these phosphors, the energy lost by an excited electron (e) results in light emitted with that energy.

References
5. www.sc-i-do.org/resource/materialscience/color/

Light absorption

Water in a glass does not appear colored because the short path of light through the glass of water results in almost no light absorption.

Leaves are dark green because they absorb almost all of the red and blue part of the visible spectrum and much of the green; they reflect a small portion of the green. Much of the absorbed light is used for photosynthesis; the remaining absorbed light heats the plant.

Deep water appears blue because absorption of visible light by water is gradual as well as selective greatest at the red end of the spectrum, least at the violet and blue end.
Misconceptions about seasons

Two factors resulting from the tilt of the Earth’s axis account for seasonal weather changes. First, in summer the Sun shines higher in the sky and its rays beat more directly down, warming the surfaces they contact. In the winter when the Sun is lower in the sky, its light reaches the ground at a lower angle, spreading out its warming ability. This is the phenomenon sometimes referred to as “indirect rays.”

Variations in the Length of Daylight

The second factor contributing to the seasons is the length of the daylight period. Because of the tilt of the Earth’s axis, daylight lasts longer in the summer than in the winter. The farther you travel from the equator, the more extreme this contrast becomes. So not only is the Sun’s warming light less effective in the winter but there are fewer hours of it. Also, the Earth’s surface has more time to cool off at night in winter than in summer.

From: A Private Universe Teacher’s Guide, p. 18
A guest appearance on The Big Bang Theory ...
And another
...and another
Part 3: APS/AAPT Joint Task Force on Undergraduate Physics Programs

What skills and knowledge should the next generation of undergraduate physics degree holders possess to be well prepared for a diverse set of careers?

Recall 8 when I discuss the Phys21 Supplement: Document your work in manner that is actionable and can be easily understood by a co-worker a year from now.

compadre.org/phys21

Some slides include text from Laurie McNeil’s talk at the 2017 APS March Meeting
J-TUPP MEMBERSHIP

Paula Heron, co-chair, University of Washington
Laurie McNeil, co-chair, University of North Carolina, Chapel Hill

Douglas Arion, Carthage College
Walter Buell, The Aerospace Corporation
S. James Gates, University of Maryland
Sandeep Giri, Google Inc.
Elizabeth McCormack, Bryn Mawr College
Helen Quinn, Stanford Linear Accelerator Center
Quinton Williams, Howard University
Lawrence Woolf, General Atomics Aeronautical Systems

Society liaisons:
Ted Hodapp, APS
Renee Michelle Goertzen, APS
Beth Cunningham, AAPT
Bob Hilborn, AAPT
A FEW FACTS

- 7500 people graduate with bachelor’s degrees in physics each year
- 350 people are hired as physics faculty members each year
- **5% of all physics bachelor’s eventually end up as physics professors**
- **40% of bachelor’s graduates enter the workforce immediately**
  - **61% work in the private sector**
  - 13% work in colleges and universities
  - 8% work in high schools
  - 6% work in the military
  - 5% work in civilian government or national laboratories
- 35% of physics PhD holders work in 4-year academic institutions

Various reports, AIP Statistical Research Center
Physics Career Paths

Career Options for Physicists

ATTENTION PHYSICS STUDENTS: You Have Options

Q: What can you do with a physics degree?
A: Get a PhD and become a physics professor OR...

- What comes after the PhD is not widely known in many physics departments, even though data show that only about one-third of physics bachelor’s degree recipients enroll in a physics or astronomy graduate program within one year of graduating. People with undergraduate degrees in physics pursue a variety of fascinating, fulfilling, and well-paying careers. This is evidenced by decades of data collected by the Statistical Research Center at the American Institute of Physics, illustrated below are the common paths of physics bachelor’s degree recipients based on the most recent data. Although these data are for graduates of US physics programs who remain in the United States.

- 36% attend graduate school in physics or astronomy. Most attend a PhD program. A doctorate in physics takes an average of 5 years to complete. About 80% enroll in a PhD program; the remainder choose a master’s degree program. Most are fully supported by teaching assistantships, research assistantships, or fellowships.

- Of those who start graduate school in physics or astronomy, 54% complete a PhD or master’s degree.

- 42% enter the workforce. Common employment sectors include:
  - Private sector
  - Government
  - STEM positions

- 2.5% enroll in professional degree programs or attend graduate school NOT in physics or astronomy.

- Over 7,300 physics bachelor’s degrees were awarded in the class of 2012-13. A record high! Typically:
  - Three-quarters of those who earn a physics bachelor’s degree have research experience.
  - One-third graduate with double majors in math and physics.
  - One-sixth start a two-year college.

- Within one year of earning a physics bachelor’s degree...

- 2.2% enroll in professional degree programs or attend graduate school NOT in physics or astronomy.

- About half enter an engineering program; the rest enter professional programs such as medicine, education, or another field. Physicists make some among the highest of all majors on medical school and law school admission tests the MCAT and LSAT.

- Students in professional degree programs are more likely to be self-funded than in research-based graduate programs, who usually have teaching assistantships, research assistantships, or fellowships.

The Statistical Research Center does not formally follow the career paths of these students, but we know that many go on to successful careers in engineering, management, education, law, medicine, business, and a variety of other areas.

Learn more at the Careers Toolbox website: www.spsnational.org/careertoolbox

References and Notes

The following sources were consulted in preparing this newsletter on the career opportunities after the bachelor’s degree in physics. These include online career resources and other publications:

1. Dean of Faculty and Dean of Students, Mathematics, Department of Physics and Astronomy, Spring 2012, August 2012.
Field of Employment for Physics Bachelors in the Private Sector, Classes of 2013 & 2014 Combined

- Engineering: 36%
- Computer or Information Systems: 23%
- Non-STEM: 25%
- Other STEM: 13%
- Physics or Astronomy: 5%

STEM refers to natural science, technology, engineering, and mathematics.

Figure is based on 1,141 responses

www.aip.org/statistics
Common Job Titles
of Physics Bachelor’s Recipients

Computer Hardware and Software
- Software Engineer
- Programmer
- Web Developer
- IT Consultant
- Systems Analyst
- Technical Support Staff
- Analyst

Research and Technical
- Research Assistant
- Research Associate
- Research Technician
- Lab Technician
- Lab Assistant
- Accelerator Operator
- Physical Sciences Technician

Education
- High School Physics Teacher
- High School Science Teacher
- Middle School Science Teacher

Engineering
- Systems Engineer
- Electrical Engineer
- Design Engineer
- Mechanical Engineer
- Project Engineer
- Optical Engineer
- Manufacturing Engineer
- Laser Engineer
- Associate Engineer
- Technical Services Engineer
- Application Engineer
- Development Engineer
- Engineering Technician
- Field Engineer
- Process Engineer
- Process Technician
- Product Engineer
- Product Manager
- Research Engineer
- Test Engineer
- General Engineer

This list is composed of common job titles identified by an AIP Statistical Research Center survey of physics bachelor’s degree graduates from the classes of 2009 and 2010.
To better prepare students for diverse careers does not mean abandoning the rigorous technical education that makes a physicist a physicist, nor does it mean regarding your program as providing only vocational training.

It does mean evaluating whether your department is doing its best to prepare students to compete with graduates in other fields (such as engineering) for desirable employment and career options.

It does mean that we should consider reframing education in the context of how it is used by our students.
WHAT DO EMPLOYERS WANT?

1. The ability to work well in teams—especially with people different from oneself
2. An understanding of science and technology and how they are used in real-world settings
3. The ability to write and speak well
4. The ability to think clearly about complex problems
5. The ability to analyze a problem to develop workable solutions
6. An understanding of global context in which work is now done
7. The ability to be creative and innovative in solving problems
8. The ability to apply knowledge and skills in new settings
9. The ability to understand numbers and statistics
10. A strong sense of ethics and integrity
11. Ability to make decisions and solve problems
12. Ability to sell or influence others
13. Ability to plan, organize and prioritize work
Knowledge and Skills Regularly Used by New Physics Bachelors Employed in the Private Sector, Classes of 2015 & 2016 Combined

- Work on a Team
- Solve Technical Problems
- Technical Writing
- Design & Development
- Perform Quality Control
- Use Specialized Equip.
- Programming
- Manage Projects
- Knowledge of Phys. or Ast.
- Simulation or Modeling
- Advanced Math
- Work with Customers
- Manage People
- Manage Budgets
- Employment in Engineering
- Employment in Computer Science or Information Technology

Percent regularly using knowledge or skill

Percentages represent the physics bachelors who indicated they use a knowledge or skill "daily," "weekly," or "monthly" on a four-point scale that also included "never or rarely."
LEARNING GOALS FOR PHYSICS PROGRAMS

Physics-specific knowledge, e.g.
• Apply basic laws of physics
• Solve problems involving multiple areas of physics
• Solve multidisciplinary problems that link physics with other disciplines
• Investigate how physics concepts are used in modern technology

Scientific and technical skills, e.g.
• Solve both well-posed and ill-posed problems through experiments, simulations, models
• Determine follow-on investigations
• Identify resource needs
• Competencies: instrumentation, computation, industry standard software, coding, data analytics
Communication skills, e.g.
• Communicate orally and in writing with audiences with a wide range of technical or non-technical backgrounds
• Organize and communicate ideas using words, mathematical equations, tables, graphs, pictures, diagrams
• Listening, discussing, persuading, assessing, understanding, teaching

Professional/workplace skills, e.g.
• Collegiality and collaboration in diverse teams
• Awareness of standard practices for effective resumes and job interviews
• Critical life skills: time management, listening, optimism, time management, responsibility, perseverance, ethical behavior
• Awareness of career opportunities and pathways for physics graduates
Boeing List of “Desired Attributes of an Engineer”

- A good understanding of engineering science fundamentals
  - Mathematics (including statistics)
  - Physical and life sciences
  - Information technology (far more than “computer literacy”)
- A good understanding of design and manufacturing processes (i.e., understands engineering)
- A multi-disciplinary, systems perspective
- A basic understanding of the context in which engineering is practiced
  - Economics (including business practice)
  - History
  - The environment
  - Customer and societal needs

- Good communication skills
  - Written
  - Oral
  - Graphic
  - Listening
- High ethical standards
- An ability to think both critically and creatively - independently and cooperatively
- Flexibility. The ability and self-confidence to adapt to rapid or major change
- Curiosity and a desire to learn for life
- A profound understanding of the importance of teamwork.

*This is a list, begun in 1994, of basic desirable attributes into which can be mapped specific skills reflecting the diversity of the overall engineering environment in which we in professional practice operate.*
*This current version of the list can be viewed on the Boeing web site as a basic message to those seeking advice from the company on the topic. Its contents are also included for the most part in ABET EC 2000.*

Resources

• Phys21 Report and Supplement
  • [https://www.compadre.org/JTUPP/](https://www.compadre.org/JTUPP/)
• Physics Today article on Phys21
• APS News Backpage article on Phys21
• AIP Career Pathways Project
  • [https://www.spsnational.org/career-resources/career-pathways](https://www.spsnational.org/career-resources/career-pathways)
• APS Physics Career Guidebook