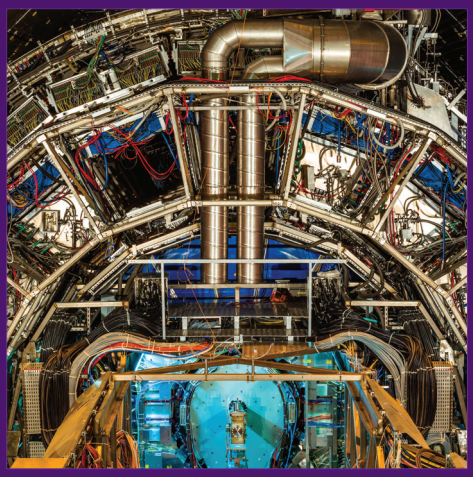
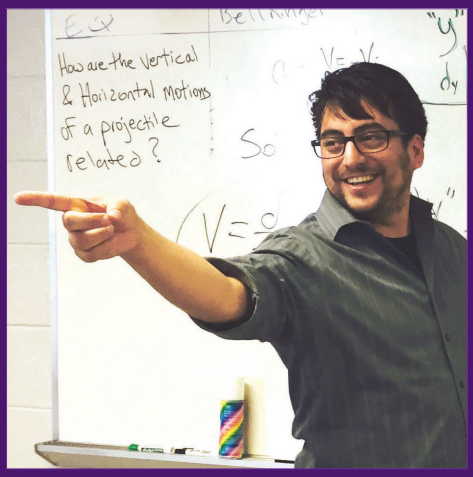
Phys21:

Supplement to Phys21: Preparing Physics Students for 21st-Century Careers

Summary of Background Reports on Careers and Professional Skills

Lawrence Woolf and Douglas Arion





JTUPP
JOINT TASK FORCE ON
UNDERGRADUATE
PHYSICS PROGRAMS

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J-TUPP Summary of Background Reports on Careers and Professional Skills
A report by the Joint Task Force on Undergraduate Physics Programs

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J-TUPP is a joint task force of:

the American Physical Society
and the American Association of Physics Teachers
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Overview

The J-TUPP committee evaluated many reports from a variety of disciplines and perspectives in order to address two major issues: (1) What do industry, employment, and hiring experts expect of STEM graduates in terms of skills, knowledge, and attitudes, and what are the prospects for those graduates in the current and near-term job market? (2) What are physics and other academic disciplines doing to address the employment needs of their respective graduates? The reports that were studied to address these questions were authored by professional societies, business and economic development groups, educational institutions, and professional consulting organizations.

In the List of Resources we have organized the reports into categories. The recommendations and conclusions from these reports are generally consistent with each other, reinforcing those made in the Phys21 report. The J-TUPP committee used these recommendations in developing the set of specific learning goals that undergraduate physics students should attain to make them well prepared for 21st century careers. This document provides context and summaries for each report, focusing on those aspects that correlate with learning goals. The lists and tables shown in this summary are generally direct quotes from the text of the reports Readers are encouraged to review the original reports for additional context and details.

List of Resources

1 Disciplinary reports

Studies done by panels in a variety of disciplines identified expectations for graduates for employability. The following summaries identify those characteristics, and those which are common across disciplines.

1A. Undergraduate Chemistry Education: A Workshop Summary (2013)

http://www.nap.edu/catalog/18555/undergraduate-chemistry-education-a-workshop-summary

On May 22-23, 2013, the National Research Council's (NRC's) Chemical Sciences Roundtable (CSR) convened a public workshop, Undergraduate Chemistry Education, in Washington, D.C. The workshop explored drivers of science education reform and innovative approaches being implemented within chemistry departments to respond to some of these drivers.

The report noted that the current strategy in introductory chemistry is to present lectures and text material that covers the basic formalism and theory, followed by problem sets and exams. A problem with this "formalism first" approach to teaching is that it results in "disembodied knowledge"– students cannot attach the knowledge to a context or their past experience, and so it is largely meaningless symbols and facts to memorize. A number of curricula that have been developed that link concepts with applications and contexts were noted in this report, including the Harvard Physics 11 (Foundations and Frontiers of Modern Chemistry: A Molecular and Global Perspective) course that links physics and chemistry concepts with context; the chemistry curriculum at UC Berkeley designed around core ideas in chemistry such as matter, change, energy, and light, similar to the structure of the Next Generation Science Standards; and the Integrated Concentration in Science (iCons) program, where groups of students with diverse backgrounds work in teams to develop solutions to today's major problems that will produce the next generation of leaders in science and technology who have the attitudes, knowledge, and skills needed to solve the inherently multifaceted problems facing the world.

Industrial participants noted that they need scientists that understand how to think, problem solve, and have the technical background and inquisitiveness, but who are not necessarily focused on a particular discipline. Having laboratory experience and putting into practice what they learn in the classroom give students a big advantage when they come into industry. Also key are learning the fundamentals of chemistry, the need for technical flexibility, and soft skills, such as collaboration, communication and interdisciplinary research in a team context.

1B. Summary Report for Summit on Future of Undergraduate Geoscience Education January 10-12, 2014

http://www.jsg.utexas.edu/events/files/Future_Undergrad_Geoscience_Summit_report.pdf

This summit was tasked to develop a community vision for the geosciences, focusing on curriculum, content, competencies, and skills; pedagogy and the use of technology; and broadening participation and retention of underrepresented groups and preparation of K-12 science teachers.

This report presented a consensus document that indicated that students need to have competencies and skills universally accepted for scientists in general, including thinking critically and solving complex problems; and be able to think like a scientist and continue to learn after they complete a degree. They should have a fundamental understanding of the major concepts of geoscience. As geoscientists, they need to be able to think spatially and temporally, inductively and deductively, make and use indirect observations, engage in complex open and coupled systems thinking. Students need to work in teams within and across disciplines, to visualize the world in 3D (and 4D), to work with uncertainty, ambiguity, incomplete data, and non-uniqueness, and make interpretations based on indirect observations. Moreover, they need to be able to communicate effectively with other scientists and non-scientists.

They should have very strong computational skills and the ability to manage and analyze large datasets and have a strong understanding of basic cognate sciences and understand basic scientific research methods. Graduates should be able to solve problems in a practical fashion, surmounting obstacles and accessing available resources. They must work effectively in interdisciplinary teams and across cultures.

The challenge for educators going forward will be to build deep understanding of the nature of the geosciences while still promoting an appreciation of the breadth of the discipline. What is important is that students are prepared to continue to learn as the geosciences grow and change and as the students' interests and employment change.

1C. Adapting to a Changing World--Challenges and Opportunities in Undergraduate Physics Education

http://www.nap.edu/catalog/18312/adapting-to-a-changing-world-challenges-and-opportunities-in-undergraduate-physics-education

The Committee on Undergraduate Physics Education Research and Implementation was tasked to identify the goals and challenges facing undergraduate physics education and identify how best practices for undergraduate physics education can be implemented on a widespread and sustained basis

This group reported that the physics community remains in a traditional mode in which the primary purpose of physics education is to create clones of the physics faculty. In addition, the subject matter and skills that undergraduates study have remained largely static for more than 50 years. Students learn little about current discoveries and research, which they might find exciting or relevant to their lives.

The future careers of undergraduate physics majors will involve critical and creative thinking and reasoning, abstract analytical skills, imagination, and judgment. They will require the ability to learn and create new things, which could be a product, insight, or service as well as to understand complex systems and manage large data sets. Higher education must prepare graduates for an international arena in which being competitive requires the ability to communicate and collaborate.

Students should learn to "think like physicists." Besides understanding of concepts graduates should be able to address open-ended, novel, challenging questions in ways that build toward professional expertise.

The report recommended that departments implement physics-specific learning goals, recognizing the different needs and views of students, employers, teachers, and alumni. Students should develop skill sets that prepare them for future learning, employment, and participation in the scientific enterprise. These would include oral and written scientific communication, understanding statistical methods and numerical simulation, becoming familiar with current physics research, and participating in a research experience.

1D. Transforming Undergraduate Education in Engineering; Phase I: Synthesizing and Integrating Industry Perspectives; May 9-10, 2013 Workshop Report

http://www.asee.org/TUEE_PhaseI_WorkshopReport.pdf

The engineering community, which as a whole has made a substantial effort to prepare students for industrial/private sector employment, has studied a variety of aspects of the academic to industry transition, and needed outcomes from undergraduate engineering education. The American Society for Engineering Education addresses these issues. Their 2013 report, a result of a three-day workshop plus pre- and post- surveys engaged nearly 50 engineering professionals in a variety of positions and engineering academics, proposed a number of observations, outcomes, and needs, both now and projected 10 years into the future. The outcomes of this study include the following:

- Engineering graduates are very good technically – but may be over-prepared in some areas, including mathematical tools which can be obtained on an as-needed basis
- Interdisciplinary work and experience are more important than course performance
- Graduates are weak in economics, business, project management, product development, systems integration, leadership, communication, and decision making
- Academia needs more input from industry and more partnerships with industry
- Responsibilities for providing the knowledge, skills, and attitudes (KSA) that industry ultimately requires vary depending on the particularly area of expertise: Some are best provided by academia, some by industry, some by parents and society, but most require input from more than one source. In particular, academia was seen as most responsible for teamwork skills, entrepreneurship, critical thinking, application-based research, data interpretation and visualization, and real-world application of engineering core sciences. Industry was seen as most responsible for risk taking, project management, ability to use new technologies, and security knowledge.
- Internships and real-world experiences are needed well before capstone projects.

High priority Knowledge Skills and Abilities crucial for the engineering profession are:

- Good communication skills
- Physical sciences and engineering science fundamentals
- Systems integration
- Curiosity and persistent desire for continuous learning
- Self-drive and motivation
- Cultural awareness in the broad sense (nationality, ethnicity, linguistic, gender, sexual orientation)
- Economics and business acumen
- High ethical standards, integrity, and global, social, intellectual, and technological responsibility
- Critical thinking
- Willingness to take calculated risk
- Ability to prioritize efficiently
- Project management (supervising, planning, scheduling, budgeting, etc.)
- Teamwork skills and ability to function on multidisciplinary teams
- Entrepreneurship and intrapreneurship

Lower priority Knowledge Skills and Abilities that are also important are:

- Ability to use new technology and modern engineering tools necessary for engineering practice
- Public safety
- Informational technology (IT)
- Applied knowledge of engineering core sciences and implementation skills to apply them in the real world
- Data interpretation and visualization
- Security knowledge (cyber, data, etc.)
- Leadership
- Creativity
- Emotional intelligence
- Application based research and evaluation skills
- Ability to create a vision
- Good personal and professional judgment
- Mentoring skills
- Flexibility and the ability to adapt to rapid change
- Ability to deal with ambiguity and complexity
- Innovation
- Technical intuition/metacognition
- Understanding of design
- Conflict resolution
- Ownership and accountability

1E. Vision and Change in Undergraduate Biology Education: A Call to Action

www.visionandchange.org

In July 2009, NSF and AAAS hosted an invitational conference on Vision and Change in Undergraduate Biology Education.

During the national conference, participants made recommendations about (1) what students should know and be able to do in the set of courses that make up the biology curriculum; (2) innovative pedagogy and the integration of authentic research experiences into individual courses and biology programs overall; (3) assessment; (4) professional development for both current and future faculty; (5) the kinds of changes that are needed at the institutional level; and (6) tools to facilitate and support change at various levels. Those recommendations formed the foundation for this report.

Learning goals should be defined so that they focus on teaching students the core concepts. Abstract concepts as well as problems in biology should be related to real-world examples. Classes should include projects where knowledge and skills are applied. Case studies should be used. There should be more connections across the disciplines (e.g., between chemistry and biology and between physics and biology) and well as greater discussion about these connections. Student should learn how to work with real data; learn to deal with ambiguity and that science can be messy. Students should become life-long learners.

Undergraduate biology education must become more concept oriented and concentrate more on integrating factual knowledge within those concepts. Students need to understand how to integrate facts into a larger conceptual context so that they become more engaged with the science, more curious, and better able to pursue questions on their own. Biology courses and curricula should focus on the conceptual framework on which the science itself is built and from which discoveries emerge. This focus is increasingly interdisciplinary, which demands quantitative competency, and requires facts as a means of illustrating concepts rather than as items to be memorized.

Core concepts for biological literacy are evolution; structure and function; information flow, exchange, and storage; pathways and transformations of energy and matter; and systems.

Core competencies and disciplinary practice are: ability to apply the process of science; ability to use quantitative reasoning; ability to use modeling and simulation; ability to tap into the interdisciplinary nature of science; ability to communicate and collaborate with other disciplines; ability to understand the relationship between science and society.

1F. 2015 Workshop Report on National Issues in Industrial Physics

https://www.aps.org/units/fiap/meetings/upload/workshop14.pdf

The American Physical Society and its Forum on Industrial and Applied Physics jointly held a workshop on national issues in industrial physics October 6-7, 2015. Senior and mid-level industrial physicists met to identify and prioritize issues important to U.S. industrial physics.

While mostly focused on graduate-level physicists, this report also has relevance for undergraduate physics majors. For success in industry, the ability to translate basic physics knowledge into application-oriented solutions remains the forte of industrial physicists. Once hired, industrial physicists must quickly learn and become proficient in the basic aspects of industry: accountability, dealing with constraints, identification and focus on the customer, active listening, business practices (business case development, return on investment, deadlines, sunk costs), rapid problem solving, working in teams, multidisciplinary projects, communication skills, and importance of profit. Career guidance is too narrow and there is a lack of mentorship for non-academic careers. Lack of exposure to non-academic careers is exemplified by the small number of industrial internships, few on-campus speakers from industrial physics, and few opportunities to network with industrial physicists.

There are deficits in hands-on experimental skills and software skills, due to highly automated equipment and analysis packages now available. This limits the hands-on experimental experience that is often valuable in industrial settings; it also limits software skills that must be learned on the job. Teamwork skills are critical, since most work occurs in a team environment. Communication skills are also critical; one needs to be able to succinctly and accurately describe work to knowledgeable, or more importantly, non-knowledgeable people. Industrial physicists need to be able to describe problems or unexpected results, and write precisely and concisely, especially for management. Listening and understanding the ideas of others is also important.

Interdisciplinary science is also a mainstream part of industrial physics, as combinations of chemistry, materials science, engineering, biology, and medicine are often woven into products. Understanding the technology development process that converts basic research to products as well as project management skills are also useful, but not usually taught.

1G. The "BYO-CEO" focus group convened in association with the APS April meeting in Denver in 2013

A "BYO-CEO" focus group was convened in association with the APS April meeting in Denver in 2013. Panelists included

- Scott Davis, physics PhD recipient and co-founder and VP of Vescent Photonics

- Henry Kapteyn & Margaret Murnane, CU Boulder physics professors who created the company K&M Labs
- John Cary, CU Boulder physics professor who created the company Tech-X
- Nathan Seidel, founder & CEO of Sparkfun, and Aaron Weiss –physics BS degree recipient who worked at Sparkfun (and now works at Google)

These represent a cross-section of physics-based and physics-related companies in the Denver/Boulder region of Colorado. The session was held to solicit input from physicists in industrial positions on the expectations for new hires from physics programs, and opportunities for physics graduates in diverse industry and career environments. Randall Tagg of UC-Denver organized the session in partnership with Crystal Bailey of the American Physical Society.

Key findings are that physics graduates are sought after in the workplace for the following skills/ abilities:

- Could easily grasp new knowledge and concepts
- Were able to identify, formulate, and solve problems
- Were able to successfully analyze and interpret data
- Could competently use computer applications and databases
- Were able to use current techniques/tools for technical practices
- Could engage in continued learning and problem solving

The survey also identified failings among such graduates, the main items being:

- Ability to design a system, component, or process to meet a specific need
- Ability to function on multi-disciplinary teams
- Ability to recognize value of diverse relationships (customers, supervisors, etc.)
- Having leadership skills
- Familiarity with basic business concepts (i.e. cost-benefit analysis, funding sources, IP, project management)
- Communication skills (oral and written) – especially how to tailor messages to diverse audiences, such as customers
- Real-world experience in companies before graduation
- Awareness of career paths outside of academia

1H. Transforming the Preparation of Physics Teachers: A Call to Action A Report by the Task Force on Teacher Education in Physics (T-TEP) edited by David E. Meltzer, Monica Plisch, and Stamatis Vokos

http://www.phystec.org/webdocs/2013TTEP.pdf

In response to the shortage of physics teachers in the U.S. and concerns about their effectiveness, the American Physical Society, American Association of Physics Teachers, and American Institute of Physics charged the Task Force on Teacher Education in Physics (T-TEP) to document the state of physics teacher preparation and make recommendations for the development of exemplary physics teacher education programs. The report made a number of findings and recommendations. The recommendations for physics departments encompassed their commitment, quality, and capacity. These recommendations have implications for the preparation of future physics majors, the quality of future high school physics teachers, and the education of undergraduate physics majors planning to become high school physics teachers. The quality recommendations are listed below.

Quality: All components of physics teacher preparation systems should focus on improving student learning in the pre-college physics classroom. Recommendations 9(a) and 9(b) are intended to be implemented together to ensure that a higher standard for quality of preparation does not increase the length and cost of the program nor decrease the number of teachers who are qualified to teach more than one subject.

6 . Teaching in physics courses at all levels should be informed by findings published in the physics education research literature.

7. Physics teacher preparation programs should provide teacher candidates with extensive physics-specific pedagogical training and physics-specific clinical experiences.

8. Physics teacher education programs should work with school systems and state agencies to provide mentoring for early career teachers.

9. (a) States should eliminate the general-science teacher certification and replace it with subject-specific endorsements; (b) Higher education institutions should create pathways that allow prospective teachers to receive more than one endorsement without increasing the length of the degree.

10. National accreditation organizations should revise their criteria to better connect accreditation with evidence of candidates' subject-specific pedagogical knowledge and skill.

11. Physics education researchers should establish a coordinated research agenda to identify and address key questions related to physics teaching quality and effective physics teacher preparation.

1I. Strategic Programs for Innovations in Undergraduate Physics: Project Report edited by Robert C. Hilborn, Amherst College, Ruth H. Howes, Ball State University, and Kenneth S. Krane, Oregon State University

https://www.aps.org/programs/education/undergrad/faculty/spinup/upload/SPIN-UP-Report.pdf

This report described the results of the Strategic Programs for Innovations in Undergraduate Physics (SPIN-UP) project, which was organized by the National Task Force on Undergraduate Physics. The goal was to determine the characteristics of undergraduate physics programs that were thriving as measured by their success in increasing the number of graduates relative to other physics departments and what lessons could be learned to help other departments become comparably thriving. Those key elements were:

- A widespread attitude among the faculty that the department has the primary responsibility for maintaining or improving the undergraduate program. The department initiated reform efforts in areas that it identified as most in need of change.
- A challenging, but supportive and encouraging undergraduate program that includes well-developed curriculum, advising and mentoring, an undergraduate research participation program, and many opportunities for informal student-faculty interactions enhanced by a strong sense of community among the students and faculty.
- Strong and sustained leadership within the department and a clear sense of the mission of its undergraduate program.
- A strong disposition toward continuous evaluation of and experimentation with the undergraduate program

More specifically, thriving undergraduate physics program included the following characteristics.

Leadership

1. Sustained leadership with a focus on undergraduate physics within the department.

2. A clearly articulated undergraduate mission and a vision of how that mission supports the mission of the institution.

3. A large fraction of the departmental faculty actively engaged in the undergraduate program.

4. Administrative support from the dean/provost for the department's undergraduate efforts.

Supportive, Encouraging and Challenging Environment

1. Recruitment program either with high school students or with first-year students at the institution.

2. A strong academic advising program for physics majors that actively reaches out to the students.

3. Career mentoring: an active effort to make students (particularly beginning students) aware of the wide range of careers possible with a physics degree. For upper-level students the mentoring includes advice on how to apply for jobs, graduate schools, etc.

4. Flexible majors' program: Several options or tracks leading to the bachelor's degree are available (and promoted).

5. 3/2 dual-degree engineering programs, particularly at four-year colleges without engineering departments.

6. Mentoring of new faculty, particularly for teaching.

7. Active physics club or Society of Physics Students chapter.

8. Student commons room or lounge.

9. Opportunities for informal student/faculty interactions.

10. Alumni relations; Alumni provide important feedback to the department and whose careers exemplify employment opportunities and are potential colloquia speakers.

Experimentation and Evaluation

1. Special attention paid to the introductory physics courses, with the "best" teachers among the faculty assigned to those courses.

2. Undergraduate research either during the summer or during the academic year. Students gain experience with the often ill-defined nature of scientific research, communication of results, and working in teams.

3. Faculty are aware of the findings of physics education research and pedagogical innovations based on physics education research.

1J. Developing a National STEM Workforce Strategy: A Workshop Summary; September 21-22, 2015

http://www.nap.edu/21900

To inform the National Science Foundation's Directorate on Education and Human Resources on how to prepare a broad and diverse U.S. STEM workforce for the 21st century, the Academies brought together about 150 interested stakeholders on September 21–22, 2015 in Washington, D.C.

The following issues emerged during the workshop:

- There is a need to bridge the significant gap between the knowledge, skills, and abilities sought by employers, such as data analysis, problem solving, creativity, teamwork, and interpersonal communication, and those of graduating students.
- There is a need for greater emphasis on interdisciplinary and transdisciplinary approaches to classroom instruction and labs at both the undergraduate and graduate levels.
- More work-based learning may be useful for students to develop key skills for career success, such as teamwork, problem solving, and communication. STEM employers should be more involved in curriculum design, and more students and faculty need to spend time in industry.

A useful interactive, online tool created by the U.S. Census Bureau allows for exploration of the relationship between college majors and occupations.

https://www.census.gov/dataviz/visualizations/stem/stem-html/

While academic curiosity, critical thinking and problem solving skills are important, students need to know how to apply their skills and knowledge to the wide variety of jobs and over many fields. Students need to be exposed to both theory and real-world problem solving. They need business and social acumen, have an entrepreneurial mindset, and know how to create a resume/cover letter and how to interview for jobs. Students need to be prepared for lifelong learning as well as flexibility and adaptability, traits needed for career success. There is a need to map technical knowledge into an academic framework, and then incorporate the other skills needed by employers. Some of these other skills include grit, curiosity, and persistence. They need the ability to collaborate with people from other disciplines, to understand the big picture and context of their work, and to communicate the importance of their work.

There is a recognized disconnect between what industry leaders say they need and what academics believe they are providing as skills and competencies. Business leaders think that students are least prepared in leadership skills, but also in professional and technical skills. While graduate schools provide excellent technical skills and training, students need other skills to be successful in employment, such as project management, communication, entrepreneurship, conflict resolution, intercultural cooperation, leadership, teamwork and collaboration, and communicating with the wide variety of people in the workplace as well as the public. Other useful skills include active listening and the ability to change behaviors based on feedback from employers. There is a need for more career centers, the development of stronger connections with alumni, and data on the career pathways of alumni.

2 Learning goals for STEM disciplines

A number of reports specifically addressed learning goals recommended for their respective disciplines. It is instructive to identify those goals which are translatable to the physics environment, and which are common among many disciplines. The following summaries address these topics.

2A. 2015 Committee on the Undergraduate Program in Mathematics CUPM Curriculum Guide to Majors in the Mathematical Sciences

http://www.maa.org/programs/faculty-and-departments/curriculum-department-guidelines-recommendations/cupm

This report found that departments have expanded their scope, incorporating more statistics and probability, computing, discrete methods and operations research. Many mathematical sciences programs are becoming more applied and more interdisciplinary. The purpose of the Guide was to help departments adapt their undergraduate curricula to this landscape while maintaining the essential components of the traditional mathematics major. The cognitive and content goals reflect the common elements of an undergraduate mathematics major. The goals below are quoted directly from the Guide, although they were selected to be those most related to the J-TUPP report. For further details, consult the entire Guide.

Cognitive Recommendation 1: *Students should develop effective thinking and communication skills.*

- identify and model essential features of a complex situation, modify models as necessary for tractability, and draw useful conclusions;
- use and compare analytical, visual, and numerical perspectives in exploring mathematics;
- assess the correctness of solutions, create and explore examples, carry out mathematical experiments, and devise and test conjectures;
- read mathematics with understanding;
- communicate mathematical ideas clearly and coherently both verbally and in writing to audiences of varying mathematical sophistication;
- approach mathematical problems with curiosity and creativity and persist in the face of difficulties;
- work creatively and self-sufficiently with mathematics.

Cognitive Recommendation 2: *Students should learn to link applications and theory.*

Mathematics students should encounter a range of contemporary applications that motivate and illustrate the ideas they are studying, become aware of connections to other areas (both in and out of the mathematical sciences), and learn to apply mathematical ideas to problems in those areas. Students should come to see mathematical theory as useful and enlightening in both pure and applied contexts.

Cognitive Recommendation 3: *Students should learn to use technological tools.*

Mathematical sciences major programs should teach students to use technology effectively, both as a tool for solving problems and as an aid to exploring mathematical ideas. Use of technology should occur with increasing sophistication throughout a major curriculum.

Cognitive Recommendation 4: *Students should develop mathematical independence and experience open-ended inquiry.*

A mathematical sciences major should be structured to move students beyond the carefully choreographed mathematical experiences of the classroom. A major curriculum should gradually prepare students to pursue open-ended questions and to speak and write about mathematics with increasing depth and sophistication.

Content Recommendation 1: *Mathematical sciences major programs should include concepts and methods from calculus and linear algebra.*

Content Recommendation 2: *Students majoring in the mathematical sciences should learn to read, understand, analyze, and produce proofs at increasing depth as they progress through a major.*

Content Recommendation 3: *Mathematical sciences major programs should include concepts and methods from data analysis, computing, and mathematical modeling.*

Working mathematicians often face quantitative problems to which analytic methods do not apply. Solutions often require

data analysis, complex mathematical models, simulation, and tools from computational science. To meet these workplace expectations every mathematical sciences major should have, at a minimum:

- a command of data analysis and statistical inference at a level equivalent to that attained in an applied data analysis course;
- experience working with professional-level technological tools such as computer algebra systems, visualization software, and statistical packages;
- modest experience writing computer programs;
- experience tackling ill-posed real-world problems by building and analyzing appropriate deterministic and stochastic mathematical models .

Content Recommendation 4: *Mathematical sciences major programs should present key ideas and concepts from a variety of perspectives to demonstrate the breadth of mathematics.*

Programs should present key ideas from a variety of perspectives, employ a broad range of examples and applications to motivate and illustrate the material, promote awareness of connections to subjects both within and beyond the mathematical sciences, and strengthen each student's ability to apply the course material to these subjects. Programs should introduce historical and contemporary topics and applications, highlighting the vitality and importance of modern mathematics, and the contributions of diverse cultures.

Content Recommendation 5: *Students majoring in the mathematical sciences should experience mathematics from the perspective of another discipline.*

Applications of mathematics to other fields continue to evolve and expand. Mathematics students should encounter substantive applications throughout the curriculum. When possible, these applications should include perspectives of non-mathematicians who use mathematics to clarify or extend their own subject.

Content Recommendation 7: *Mathematical sciences major programs should require the study of at least one mathematical area in depth, with a sequence of upper-level courses.*

Content Recommendation 8: *Students majoring in the mathematical sciences should work, independently or in a small group, on a substantial mathematical project that involves techniques and concepts beyond the typical content of a single course.*

Every major student should have a "high impact" experience that requires substantial work in mathematics outside the carefully scripted confines of ordinary course work. Students should present their results in written and oral form. Institutions can provide this opportunity in various ways: undergraduate research experiences, courses driven by inquiry or open-ended problem solving, capstone courses, internships or jobs with a substantial mathematical component, etc.

Content Recommendation 9: *Mathematical sciences major programs should offer their students an orientation to careers in mathematics.*

2B. Undergraduate Professional Education in Chemistry: ACS Guidelines and Evaluation Procedures for Bachelor's Degree Programs

http://www.acs.org/content/dam/acsorg/about/governance/committees/training/2015-acs-guidelines-for-bachelors-degree-programs.pdf

The American Chemical Society (ACS) charged the Committee on Professional Training (CPT) with the development and administration of guidelines for program approval and student certification. The guidelines for student skills demonstrate that to prepare students to enter the workforce or postgraduate education, a student must develop both chemistry content knowledge as well as other critical skills necessary to be a professional chemist. The set of student skills deemed critical are described below as per section 7 of this report.

Problem Solving Skills. Students should be able to define problems, develop testable hypotheses, design and execute experiments, analyze data using appropriate statistical methods, understand uncertainties in experimental measurements, and draw conclusions. They should be able to apply their understanding of chemistry subdisciplines and use laboratory skills and instrumentation to solve problems.

Chemical Literature and Information Management Skills. Students should be able to retrieve information efficiently and effectively by searching the chemical literature and evaluate technical articles critically. They should be able to read, analyze, interpret, and cite the chemical literature.

Laboratory Safety Skills.

Communication Skills. Students should learn to present information in a clear and organized manner, write well-organized and

concise scientific reports, and use relevant technology.

Team Skills. Students should be able to work in diverse multidisciplinary teams so that they can interact effectively and work productively to solve scientific problems and they should develop leadership skills.

Ethics. Students should be trained in the responsible treatment of data, proper citation of others' work, and the standards related to plagiarism and the publication of scientific results. Students should be exposed to the role of chemistry in contemporary societal and global issues.

2C. CRITERIA FOR ACCREDITING ENGINEERING PROGRAMS: Effective for Reviews During the 2015-2016 Accreditation Cycle

http://www.abet.org/wp-content/uploads/2015/05/E001-15-16-EAC-Criteria-03-10-15.pdf

This document contains two relevant sections regarding outcomes. The second section contains the General Criteria for Baccalaureate Level Programs that must be satisfied by all programs accredited by the Engineering Accreditation Commission of ABET. The third section contains the Program Criteria that must be satisfied by certain programs, such as for Optics and Photonics programs.

Among the General Criteria are the following that apply to all programs:

Criterion 3. Student Outcomes

The program must have documented student outcomes that prepare graduates to attain the program educational objectives. Student outcomes are outcomes (a) through (k) plus any additional outcomes that may be articulated by the program.

(a) an ability to apply knowledge of mathematics, science, and engineering

(b) an ability to design and conduct experiments, as well as to analyze and interpret data

(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability

(d) an ability to function on multidisciplinary teams

(e) an ability to identify, formulate, and solve engineering problems

(f) an understanding of professional and ethical responsibility

(g) an ability to communicate effectively

(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context

(i) a recognition of the need for, and an ability to engage in life-long learning

(j) a knowledge of contemporary issues

(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

3 STEM competencies from the perspective of employers

It is critical to consider the perspective of those who are most likely to be employing graduates of undergraduate physics programs. They are in the best position to identify and express the skills, knowledge, and attitudes they expect of such graduates, and to evaluate the preparation of current graduates of physics programs vs. those from other disciplines. This section summarizes reports from studies conducted by a number of organizations, including employment agencies, economic think tanks, and academic researchers. The studies utilized a variety of methods, including surveys of employers and recent graduates, as well as employment and hiring statistics and economic development data.

General outcomes of these studies demonstrate the demand for technology-trained graduates. The types of career skills that are requested by employers are consistent with those reported in other studies (such as those covered earlier in this report), along with recommendations for the types of experiences that undergraduates should have to make them valuable and well-prepared employees.

3A. The Role of Higher Education in Career Development: Employer Perceptions December, 2012

https://chronicle.com/items/biz/pdf/Employers%20Survey.pdf

This report accrued recommendations from employers regarding their expectations for experiences expected of college graduates to make them suitable for hiring. The list below makes clear that internships – real world experiences in the industries in which students wish to work – are a primary expectation for hiring. In contrast with physics, the engineering curriculum with its emphasis on industrial partnerships, internships, and co-ops, gives graduates a leg up on physics students who could easily perform the same jobs. Providing these kinds of experiences to physics students will help address some of the educational and qualification short falls they currently experience.

Element	Relative Importance (Scale of 100)
Internships	23
Employment during college	21
College major	13
Volunteer experience	12
Extracurricular activities	10
Relevance of coursework	8
College GPA	8
College reputation	5

The following table summarizes the top skills that graduates have vs. perceived need. It is interesting to identify those areas where the perceived need exceeds the actual experience of graduates – these certainly define areas where greater preparation at the undergraduate level is needed.

Skill	% Needing Skill	% Having Skill
Written and Oral Communication Skills	75	60
Adaptability/managing multiple priorities	50	25
Making decisions/solving problems	60	30
Collaborating with others	50	50
Planning/organizational skills	45	25
Technical skills associated with jobs	75	65
Knowledge of a content area associated with the job	45	55
Working with diverse groups of people	35	35
Analytical/research skills	45	45
Leading teams	5	5

3B. Association of American Colleges and Universities: Top Ten Things Employers Look for in New College Graduates

http://www.aacu.org/leap/students/employers-top-ten

The diversity of skills – and the need for great flexibility in the near-future workforce – are well described in the following set of recommendations from this report:

1. The ability to work well in teams—especially with people different from yourself
2. An understanding of science and technology and how these subjects 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

Perhaps of particular note in this list – differentiating it from some others – is the mention of global context. The explicit mention of ethics is an important addition to necessary student outcomes.

3C. Still Searching: Job Vacancies and STEM Skills; Metropolitan Policy Program at Brookings

http://www.brookings.edu/research/interactives/2014/job-vacancies-and-stem-skills#/M10420

This report analyzes a new database of millions of job openings and their characteristics in terms of skills, occupations, educational requirements, location, and advertising duration. This is the largest database of vacancy duration to be analyzed, and is the first national research database of vacancy duration by skill level.

The study utilized data measuring duration of advertising for different positions, the number of advertisements per position, and the number of both available and successful candidates for these positions. This study found that, in general, regions where unemployment was low had high numbers of openings per job applicant, and that over 2/3 of positions advertised required STEM capability, in contrast with regions with high unemployment, where as few as 1/6 of positions require STEM skills. Thus, there are areas where the vast majority of STEM positions are available, but where graduates with suitable skills for the STEM workforce are not found in sufficient number, and where the jobs available generally demand STEM capable employees. The need for individuals trained in STEM but with skills suitable for private sector employment is clearly demonstrated. There is a relative shortage of U.S. workers with STEM skills, though STEM skills are in high demand relative to supply, and the problem is especially acute in certain metropolitan areas, where the average vacancy for STEM workers takes months to fill.

Among engineering skills listed that are relevant to the undergraduate physics degree are the following

- Engineering analyses
- Mathcad
- Engineering calculations
- Design of experiments (DOE)
- Materials selection
- Materials science
- Failure analysis
- Concept design and development

- Product design
- Materials engineering
- Six sigma green/black belt
- Data acquisition
- Labview
- Process control
- Product improvement
- Electromechanical design
- Materials testing
- Oscilloscopes

3D. How Should Colleges Prepare Students To Succeed In Today's Global Economy? Based On Surveys Among Employers And Recent College Graduates Conducted On Behalf Of: The Association Of American Colleges And Universities By Peter D. Hart Research Associates, Inc.

https://www.aacu.org/sites/default/files/files/LEAP/2007_full_report_leap.pdf

This study of employers identified a number of areas on which colleges and universities should place more emphasis. Interestingly, contrasting the responses from graduates to those of employers, recent graduates rank many of the same learning outcomes as top priorities, but their support for increased emphasis in many areas is less intense than employers' support.

Integrative Learning

- The ability to apply knowledge and skills to real-world settings through internships or other hands on experiences (73% report need for greater emphasis)

Knowledge of human cultures and the physical and natural world

- Concepts in new developments in science and technology (82%)
- Global issues and developments and their implications for the future (72%)
- The role of the US in the world (60%)
- Cultural values and traditions in America and other countries (53%)

Intellectual and practical skills

- Teamwork skills and the ability to collaborate with others in diverse group settings (76%)
- The ability to effectively communicate orally and in writing (73%)
- Critical thinking and analytical reasoning skills (73%)
- The ability to be innovative and think creatively (70%)
- The ability to solve complex problems (64%)
- The ability to work with numbers and understand statistics (60%)

Personal and Social Responsibility

- A sense of integrity and ethics (56%)

3E. National Association of Colleges and Employers 2013 Survey

http://www.forbes.com/sites/susanadams/2014/04/16/the-college-degrees-and-skills-employers-most-want/

A non-profit group in Bethlehem, PA, the National Association of Colleges and Employers (NACE) links college placement offices with employers. It surveyed 1,015 of its employer members from February 11 – March 26, 2014 and got responses from 161 companies in industries ranging from agriculture to energy to retail.

The NACE survey asked employers to rate the skills they most value in new hires. Companies want candidates who can make decisions, solve problems, communicate clearly, analyze data and prioritize their work. This list is specific about the ability to create and edit written material, and ability to sell and influence. These topics are not generally covered in a physics curriculum, yet are indeed central to the success of any organization.

Here is the ranking in order of importance:

- Ability to make decisions and solve problems
- Ability to verbally communicate with persons inside and outside the organization
- Ability to obtain and process information
- Ability to plan, organize, and prioritize work
- Ability to analyze quantitative data
- Technical knowledge related to the job
- Proficiency with computer software programs
- Ability to create and/or edit written reports
- Ability to sell and/or influence others

3F. Daniel Group report on what employers look for in candidates

http://www.danielgroupus.com/business-services/for-employers/what-to-look-for-in-candidates

The Daniel Group summarized a list of skills and abilities for STEM hires. This work, targeted at employers, aimed to help hiring offices better discriminate among candidates to identify those most likely to succeed in challenging positions. The recommendations were broken down into broad categories, and included:

Technical Skills

Technical skills indicate an employee's ability to complete the tasks specific to his or her position. Examples include:

- Good communication skills
- Knowledge of company specific software
- Ability to deal with customers
- Good general computer skills

Candidate Qualities

Candidate qualities include the personality traits that a candidate should possess in order to work for your company or department. Examples include:

- Professional appearance
- Self-starter
- Quick learner
- High energy
- Intelligence
- Needs minimal supervision

Soft Skills

Soft skills are the attributes that every candidate should possess. Examples include:

- Initiative

- Dependability
- Attention to detail
- Concern for others
- Independence
- Cooperation
- Stress tolerance

3G. PayScale 2016 Workforce-Skills Preparedness Report

http://www.payscale.com/data-packages/job-skills

To study workplace preparedness and gaps in skills, PayScale surveyed managers and recent college graduates in the U.S. in early 2016 who had completed the PayScale employee compensation survey. The cohort included 63,924 managers and 14,167 recent graduates. The following table identifies a set of skills and abilities that managers feel are lacking among graduates. The topics are broken into 'hard' skills and 'soft'/people skills.

Hard/Soft	Skill	% of Managers Who Feel New Grads Lack Skill
Hard	Writing proficiency	44%
	Public speaking	39%
	Data analysis (Excel, Tableau, Python, R, etc.)	36%
	Industry-specific software (Salesforce, CAD, Quickbooks, etc.)	34%
	Mathematics	19%
	Design	14%
	Coding/computer programming	12%
	Foreign language proficiency	11%
	Search engine optimization/search engine marketing	7%
Soft	Critical thinking/problem solving	60%
	Attention to detail	56%
	Communication	46%
	Ownership	44%
	Leadership	44%
	Interpersonal skills/teamwork	36%
	Grit	25%
	Curiosity	16%

4 Learning goals from university and college departments

A number of academic institutions have published their expectations for student outcomes. Several of these make recommendations that are pertinent to this report, and are summarized below.

4A. University of California – Berkeley Physics Department

http://physics.berkeley.edu/academics/undergraduate-degree/the-major-and-minor-program/goals-of-the-physics-major-usli

A student graduating from Berkeley with a major in physics will understand classical and modern physics (as outlined in the course requirements below) and will also acquire the skills to apply principles to new and unfamiliar problems. Their understanding should include the ability to analyze physical problems (often posed as "word problems"), be able to derive, and prove equations that describe the physics of the universe, understand the meaning and limitations of these equations, and have both physical and numerical insight into physical problems (e.g. be able to make order-of-magnitude estimates, analyze physical situations by application of general principles as well as by textbook type calculations). They will also have developed basic laboratory, library, and computational skills, be familiar with important historical experiments and what physics they revealed, and be able to make both written and oral presentations on physics problems posed to them. In particular, the goals are described below and are classified as knowledge-based, performance/skills based, and affective-based:

Knowledge-Based

Graduates will have:

1. Mastered a broad set of knowledge concerning the fundamentals in the basic areas of physics (quantum mechanics, classical mechanics, statistical mechanics, thermodynamics, electricity and magnetism, optics, and special relativity). This does not refer to knowledge about specific facts, but rather to a working knowledge of fundamental concepts that can then be applied in many different ways to understand or predict what nature does.
2. An understanding of the physical principles required to analyze a physical question or topic, including those not previously seen, and both quantitative and qualitative physical insight into these principles in order to understand or predict what happens. This includes understanding what equations and numerical physical constants are needed to describe and analyze fundamental physics problems.
3. A set of basic physical constants that enable their ability to make simple numerical estimates of physical properties of the universe and its constituents.
4. An understanding of how modern electronic instrumentation works, and how both classical and modern experiments are used to reveal the underlying physical principals of the universe and its constituents.
5. An understanding of how to use computers in data acquisition and processing and how to use available software as a tool in data analysis.
6. An understanding of modern library search tools used to locate and retrieve scientific information.

Performance/Skills-Based

Graduates will have the ability to:

1. Solve problems competently by identifying the essential parts of a problem and formulating a strategy for solving the problem. Estimate the numerical solution to a problem. Apply appropriate techniques to arrive at a solution, test the correctness of the solution, and interpret the results.
2. Explain the physics problem and its solution in both words and appropriately specific equations to both experts and non-experts.
3. Understand the objective of a physics laboratory experiment, properly carry out the experiments, and appropriately record and analyze the results.
4. Use standard laboratory equipment, modern instrumentation, and classical techniques to carry out experiments.
5. Know how to design, construct, and complete a science-based independent project (specifically in the area of electronics).
6. Know and follow the proper procedures and regulations for safely working in a lab.
7. Communicate the concepts and results of their laboratory experiments through effective writing and oral communication skills.

Affective

Graduates will:

1. Be able to successfully pursue career objectives in graduate school or professional schools, in a scientific career in government or industry, in a teaching career, or in a related career.
2. Be able to think creatively about scientific problems and their solutions, to design experiments, and to constructively question results they are presented with, whether these results are in a newspaper, in a classroom, or elsewhere

4B. Georgetown University Physics Department

http://physics.georgetown.edu/undergrad/physics-department-learning-goals

The programmatic learning goals for the majors and minors include both general and specific objectives, as listed below.

1. Overall knowledge and capabilities

- Knowledge of and ability to use various problem solving strategies
- Ability to justify and explain specific approaches to solving problems
- Ability to synthesize knowledge from different areas of physics
- Ability to work in teams
- Development of written and oral communication skills
- Application of knowledge to independent research projects.
- Tools and encouragement to become life-long learners
- Understanding of when numerical calculations are indicated and the ability to carry them out.

2. Specific physics knowledge

Develop a solid understanding of physics, both conceptual understanding and the ability to solve problems in the following areas.

- Introductory mechanics: fundamental principles governing momentum, energy, and angular momentum, with applications to dynamics of systems interacting via gravitational, electric, and contact forces; connections between atomic nature of matter and mechanics of macroscopic systems.
- Electricity and magnetism: conceptual understanding of electric and magnetic fields, interaction of charges and fields, Maxwell's equations, electromagnetic radiation, simple electronic circuits.
- Statistical physics: basic concepts of energy, entropy, temperature and the heat capacity of solids.
- Modern physics: special relativity, inertial reference frames, time dilation, length contraction, paradoxes, principle of equivalence; basic quantum mechanics, wave-particle duality, Schroedinger's equation, the hydrogen atom.
- Mathematical methods: develop understanding of and ability to solve problems in ordinary and partial differential equations, complex variables, linear algebra, vector algebra and calculus, partial differentiation, multiple integrals, Fourier series, integral transforms, calculus of variations, and probability.
- Experimental physics: error analysis, curve fitting, data analysis, simple electronic circuits, implementation of fundamental experiments such as optical spectroscopy, electron diffraction and interferometry; learn basic experimental methods such as lock-in amplification, analog to digital conversion, image capture, etc.

3. Advanced physics knowledge

In addition, our goal is to give students the opportunities to explore in depth two or more specialty areas at a level sufficient to prepare them for graduate coursework. These areas include biophysics, optics, microelectronics, advanced classical mechanics, advanced statistical mechanics, computational physics, particle physics, cosmology, nanoscience and soft matter physics.

4. Specific goals by degree:

B.S. students: Acquire sufficient knowledge and skills for students to be able to gain admission to and succeed in good quality physics graduate programs (top 100 physics grad schools).

A.B students: Acquire sufficient knowledge and skills for students to be able to gain admission to and succeed in graduate programs in other fields (e.g. medical school) or in jobs in industry and national labs.

Minors: Acquire a basic knowledge of physics sufficient to successfully apply to careers in science related areas, e.g. high tech business, secondary education, etc.

4C. Kettering University Applied Physics Program - Employer Work Evaluation Fall 2009 - Winter 2012

Kettering University was originally founded as an engineering school to support General Motors. Since its founding the offerings have greatly expanded, and address a full range of technology and science disciplines. A unique feature of all Kettering programs is the integration of internships and co-ops into the academic experience of students. They are required of all students, and programs normally have durations of five (rather than four) years. Two of their programs are applied physics and engineering physics. To better prepare the graduates from these two programs, Kettering engaged in a detailed survey of employers to identify the skills, knowledge, and attitudes expected of their graduates. The following summarize the key areas that employers expect of graduates. Where appropriate, they are denoted with outcomes categories specified by ABET as part of its accreditation standards. [Bahram Roughani, private communication, 2016]

- Produced quality work in terms of neatness, accuracy, and thoroughness. (quality)
- Produced an appropriate volume of work relative to expectations. (quantity)
- Managed time well. (organization)
- Exercised initiative. (proactive)
- Exhibited excellent interpersonal skills. (relations with other)
- Exhibited leadership qualities. (leadership)
- Exhibited sound judgement when making decisions. (leadership)
- Responded well to supervision. (attitude)
- Exhibited a degree of accountability for work produced. (attitude)
- Exhibited an appreciation for positive suggestions. (attitude)
- Exhibited a degree of enthusiasm for work assigned. (attitude)
- Exhibited an ability to grasp new knowledge and concepts. (ability to learn)
- Exhibited problem solving ability. (problem solving)
- Provided creative concepts and ideas relative to the improvement of group practices. (commitment to improvement)
- Exhibited a professional work ethic. (dependability)
- Exhibited a good record of attendance and punctuality. (dependability)
- Technical background necessary for the completion of assigned projects.
- Ability to apply knowledge of their field of study to assigned projects.
- Ability to design and conduct experiments.
- Ability to analyze and interpret data.
- Ability to design a system, component or process to meet a desired need.
- Ability to identify, formulate, and solve problems.
- Ability to function on multi-disciplinary (cross-functional) teams.
- Ability to use current techniques necessary to engage in technical practices.
- Ability to use modern tools necessary to engage in technical practices.
- Ability to utilize computer applications and databases.
- Familiarity with the handling of hazardous materials in the workplace.
- Exhibited an understanding of ethical responsibility.
- Exhibited proficiency in communication through speaking.
- Exhibited proficiency in communication through writing.
- Exhibited an understanding of the potential impact technical solutions have on society and the world.
- Exhibited the need for continuing the learning of (engineering, scientific, mathematical, managerial, etc.) concepts and solutions throughout the course of a career.
- Exhibited knowledge of contemporary issues pertaining to engineering, science, mathematics, and/or management.
- Student met all objectives of the work term.

4D. Austin College STAR Leadership Program

http://www.austincollege.edu/academics/experiential-learning/star-leadership-program/

The STEM Teaching and Research (STAR) Leadership Program at Austin College provides undergraduate students who take biology, chemistry, environmental science, and physics courses the opportunity to learn leadership behaviors through an integrated leadership curriculum. The program is described in the following paper:

Reed, K. E.; Aiello, D. P.; Barton, L. F.; Gould, S. L.; McCain, K.; & Richardson, J. M. (2015). Integrating Leadership Development Throughout the Undergraduate Science Curriculum, Journal of College Science Teaching 45 (5), 51-59 (2016).

The following is a summary of behavior competencies for the STAR Leadership Program.

Interpersonal communication

- Effectively communicates an idea or message in a compelling manner
- Understands the context, audience, and purpose of their communication
- Skillfully uses supporting material to strengthen their communication
- Gives and receives constructive feedback in a positive manner that leads to improvement

Problem solving

- Effectively discerns the nature of a problem
- Identifies and generates creative solutions to problems
- Exercises the ability to make concise and effective decisions in both urgent and reflective situations
- Implements a solution to a problem by considering multiple factors
- Effectively evaluates the outcomes of a solution and reflects on further work needed on a problem

Collaborative work

- Committed to creating a constructive learning environment
- Demonstrates a well-developed ability to work cooperatively with others and to motivate others to participate
- Takes responsibility within a team and brings assignments to a successful conclusion
- Responds to and actively works to resolve conflict

Foresight and planning

- Develops and utilizes their knowledge in new situations
- Is thoughtful and critically reflective resulting in personal growth
- Is a responsible manager of human and material resources
- Exercises foresight by actively assessing and planning for possible future outcomes

Moral consciousness

- Is aware of the impact of their decisions on others
- Seeks to make decisions with integrity and with regard beyond their own self-interest
- Demonstrates fairness and compassion while making decisions
- Evaluates and appropriately considers ethical complexity as a part of their decision-making process
- Is aware of their own values and the origin of those values

5 Career Pathways Project of the American Institute of Physics

The Career Pathways Project (CPP) of the AIP aims to help physics departments increase their physics bachelor's degree production by better preparing physics majors for the STEM workforce. Ten features were identified by CPP as common among departments that are effective in preparing students to enter the STEM workforce, several of which are very similar to features identified by the earlier SPIN-UP study of thriving physics departments. These are noted in the list below with an [S]. This overlap suggests that some of the features that help undergraduate physics departments thrive in terms of increasing bachelor's degree production also help them succeed when it comes to preparing students to enter the STEM workforce.

https://www.spsnational.org/career-resources/career-pathways

Curricular Features

- Varied and high-quality lab courses
- Research opportunities for undergraduates (S)
- Curricular flexibility (S)
- Building communication skills as part of the undergraduate physics experience

Extracurricular Features

- Faculty and staff commitment to physics majors' success at all levels, regardless of career goals
- Strong community of students within the physics department (S)
- Opportunities for physics majors to be involved in outreach activities
- Mentoring and advising physics majors in accordance with their interests and goals (S)
- Connections with alumni (S)
- Relationship with the career services office

Commonly used skills of physics bachelor's degree holders in the workplace

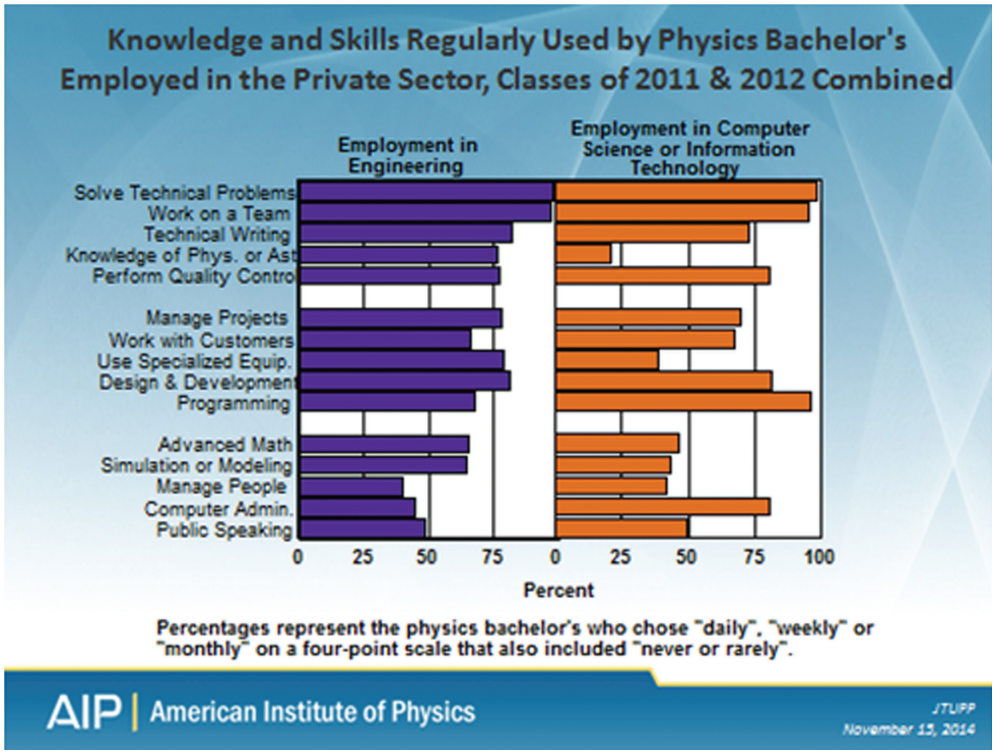
- Communicating complex ideas
- Analysis and quantitative thinking
- Working with others
- Problem solving and critical thinking
- Working with laboratory instruments
- Conducting research
- Proficiency with computer hardware and software

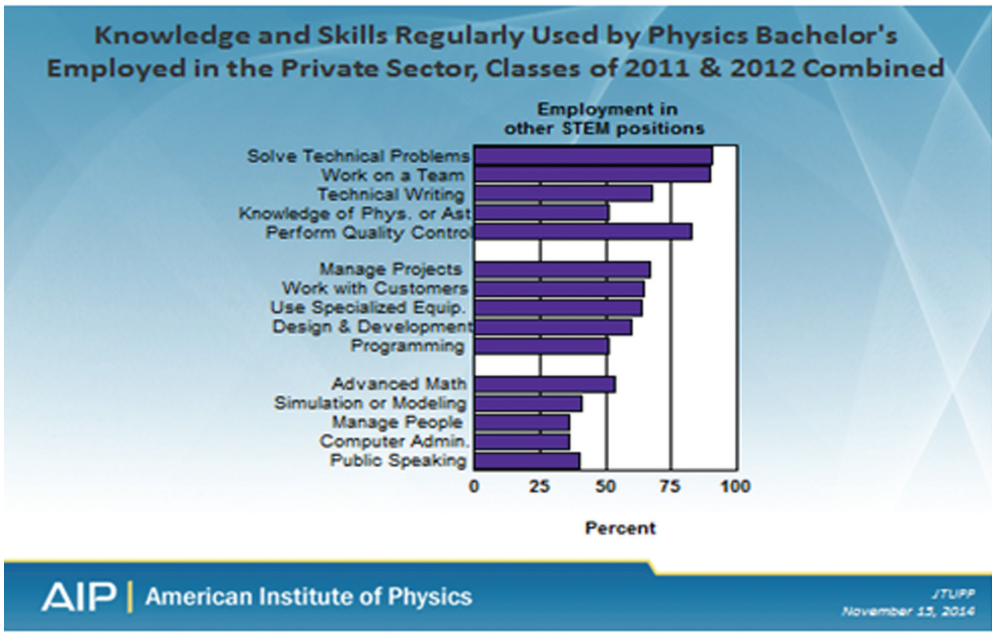
Make it easy for a potential employer to see why you are the right person for this job by highlighting your skills and experience most relevant to those listed in the description first and in the most detail.

6 AIP Statistical Research Center Reports

The American Institute of Physics operates a center that obtains data on many aspects of physics programs, graduates, and employment. A regular sequence of surveys of physics graduates, surveys of physics departments on graduation rates and graduate placement, and other related efforts provide a suite of data that give insight into the careers that students undertake and the skills and abilities needed in those jobs. The figures below are drawn from recent AIP studies, and elucidate the range of skills that are expected in the job market. It is interesting and important to note the prevalence of 'soft' skills on the list, in addition to the 'technical' skills that are typically expected.
https://www.aip.org/statistics

6A. Knowledge and Skills Used by Physics Bachelor's Employed in the Private Sector, Classes of 2011 & 2012 Combined





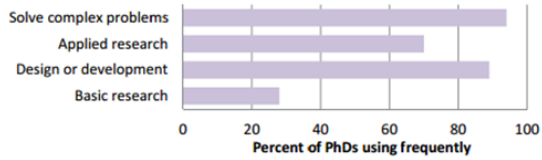
6B. Common Careers of Physicists in the Private Sector; PhDs educated in the U.S. 10-15 years earlier

https://www.aip.org/sites/default/files/statistics/phd-plus-10/PhysPrivSect.pdf

Skills used by PhD physicists in a variety of careers are documented in this report. The careers of respondents are quite broad, including those who are self-employed, in finance, working as government contractors, or primarily involved in engineering, computer science, physics, and in other STEM and non-STEM fields. The figures on the right summarize the results of these studies. As in the studies quoted earlier, these studies show the breadth of abilities that are expected of graduates (even at the PhD level), generally above and beyond what is provided during academic preparation.

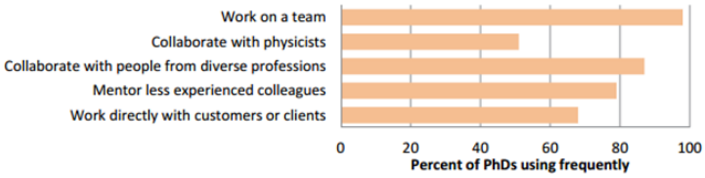
The figures to the right summarize a variety of topical areas from surveys of physicists in a variety of positions. These areas include: Cognitive skills, interpersonal skills, technical knowledge, managerial skills, and communication skills. Of the many areas shown in these figures, the prevalence of different communication skills, teamwork, and project and people management in the survey responses are significant departures from the typical preparation received by physics students, but which are common to the preparation of engineering students who also take on similar positions. Figure 7.2, in particular, indicates that interpersonal skill areas including collaboration with diverse disciplines and interacting with customers or clients are critical features of operating in industrial environments. Similarly, from figure 7.4 project management is identified as a critical capability. Neither of these areas is actually foreign to physics in many career paths, as many research areas cross disciplinary boundaries, and organizing and managing a research project of any kind depends critically on project management skills.

Figure 7.1: Cognitive Skills Used Frequently by Industrially Employed Physicists Working Primarily in Engineering



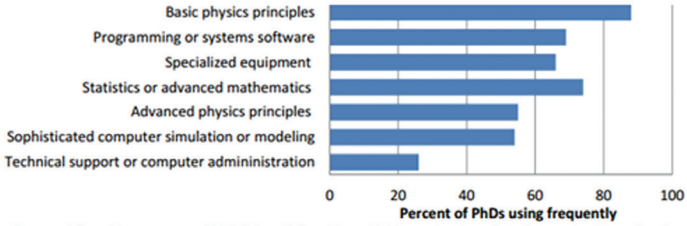
"Frequently" combines response of "daily", "weekly", and "monthly" from a 5-point scale to the question "How often do you use the following in your current job?" Data include US-educated physicists who earned their PhDs 10-15 years earlier, who were working in the US in 2011, and whose primary field of employment was engineering.
PhD Plus 10 Study - www.aip.org/statistics

Figure 7.2: Interpersonal Skills Used Frequently by Industrially Employed Physicists Working Primarily in Engineering



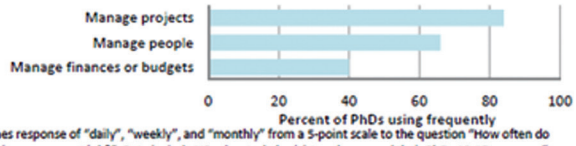
"Frequently" combines response of "daily", "weekly", and "monthly" from a 5-point scale to the question "How often do you do the following in your current job?" Data include US-educated physicists who earned their PhDs 10-15 years earlier, who were working in the US in 2011, and whose primary field of employment was engineering.
PhD Plus 10 Study - www.aip.org/statistics

Figure 7.3: Scientific and Technical Knowledge Used Frequently by Industrially Employed Physicists Working Primarily in Engineering



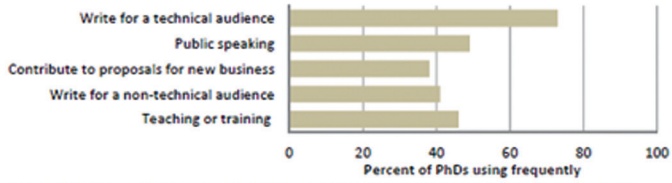
"Frequently" combines response of "daily", "weekly", and "monthly" from a 5-point scale to the question "How often do you use the following in your current job?" Data include US-educated physicists who earned their PhDs 10-15 years earlier, who were working in the US in 2011, and whose primary field of employment was engineering.
PhD Plus 10 Study - www.aip.org/statistics

Figure 7.4: Managerial Skills Used Frequently by Industrially Employed Physicists Working Primarily in Engineering



"Frequently" combines response of "daily", "weekly", and "monthly" from a 5-point scale to the question "How often do you do the following in your current job?" Data include US-educated physicists who earned their PhDs 10-15 years earlier, who were working in the US in 2011, and whose primary field of employment was engineering.
PhD Plus 10 Study - www.aip.org/statistics

Figure 7.5: Communication Skills Used Frequently by Industrially Employed Physicists Working Primarily in Engineering



"Frequently" combines response of "daily", "weekly", and "monthly" from a 5-point scale to the question "How often do you do the following in your current job?" Data include US-educated physicists who earned their PhDs 10-15 years earlier, who were working in the US in 2011, and whose primary field of employment was engineering.
PhD Plus 10 Study - www.aip.org/statistics

7 Meta-analyses of STEM competencies

7A. Identifying 21st century STEM competencies using workplace data

Hyewon Jang, Journal of Science Education and Technology April 2016, Volume 25, Issue 2, pp 284-301

This study identified important STEM competencies using the U.S. Department of Labor O*NET job-specific database. Analyzing the importance of 109 skills, types of knowledge and work activities, revealed 18 skills, seven categories of knowledge, and 27 work activities important for STEM workers, which are listed below (from Table 2 of the paper).

Skills

- Critical thinking
- Reading comprehension
- Active listening
- Speaking
- Complex problem solving
- Judgment & decision making
- Writing
- Monitoring
- Active learning
- Time management
- Coordination
- Systems analysis
- Mathematics
- Social perceptiveness
- Systems evaluation
- Instructing
- Science
- Learning strategies

Knowledge

- English language
- Mathematics
- Computers & electronics
- Engineering & technology
- Administration & management
- Customer & personal service
- Education & training

Work Activities

- Getting information
- Making decisions and solving problems
- Interacting with computers
- Communicating with supervisors, peers, or subordinates
- Updating and using relevant knowledge
- Analyzing data or information
- Identifying objects, actions, and events

- Processing information
- Documenting/recording information
- Organizing, planning, and prioritizing work
- Thinking creatively
- Establishing and maintaining interpersonal relationships
- Evaluating information to determine compliance with standards
- Interpreting the meaning of information for others
- Monitor processes, materials, or surroundings
- Communicating with persons outside organization
- Estimating the quantifiable characteristics of products, events, or information
- Judging the qualities of things, services, or people
- Training and teaching others
- Scheduling work and activities
- Developing objectives and strategies
- Coordinating the work and activities of others
- Provide consultation and advice to others
- Developing and building teams
- Inspecting equipment, structures, or material
- Coaching and developing others
- Guiding, directing, and motivating subordinates

7B. Why the Hard Science of Engineering is No Longer Enough to Meet the 21st Century Challenges

by Richard K. Miller

http://www.olin.edu/sites/default/files/rebalancing_engineering_education_may_15.pdf

This paper describes the rationale for rebalancing the engineering curriculum by incorporating professional skills. By synthesizing numerous resources, the following is a summary of professional skills, which may not be completely independent. These skills focus on a set of attitudes, behaviors, and motivations.

A Summary of Professional Skills:

- Ethical behavior and trustworthiness
- Employability skills, including self-confidence and positive outlook, accepting responsibility, perseverance, sincerity, respect for others, good judgment, etc.
- Effective communication, including advocacy and persuasion
- Effective collaboration including leadership, followership, and consensus building
- Resourcefulness and the capacity for independent learning
- Entrepreneurial mindset and associated business acumen
- Inter- and multi-disciplinary thinking
- Creativity, curiosity, and design
- Empathy, social responsibility
- Global awareness and perspective

8 J-TUPP interviews with industry leaders

The taskforce interviewed a number of industry leaders to gain additional perspective. A collection of key points and recommendations are as follows.

8A Physicist 1: Students need to participate in research, do internships, file patents, gain any kind of hands-on experience. Physics majors lack some hard skills: mechanical and circuit and optical design, statistical data analysis, automation, control software. They are generalists who have the potential to learn to do design (given chance to learn, e.g., CAD). They are not familiar with current software packages used in industry (SolidWorks, ProE, ZMax), Physics majors cannot sell themselves as problem solvers. They say "this is what my professor asked me to do, this is project I was put on, I did what I was tasked to do." He is looking for problem-solvers—tell him how you walked into a problem (equipment not working, new software to learn) and how you helped make it better. It helps to have more engineering classes and more familiarity with software packages. Physics majors are prepared to learn new things. Engineers speak with more confidence about failed experiments (this is relevant, since most products fail). How to make contacts to find sources of materials/equipment for your project, how much info to get out of the catalog vs over the phone, what is a non-disclosure agreement and when do you need one, how to analyze a quotation. He hires a physics major for a generalist role—reliability, quality, failure analysis, new product introduction. Manufacturing-related questions: I have a new technology to replace Li batteries in cell phones and I have made 10 of them so far. How would you scale to manufacturing 10,000 units? (Physics majors don't know where to start). How would you reduce the cost per unit, find sources for the necessary materials?

8B Physicist 2: He looks for physics bachelors who will work in laboratories—they need hands-on skills more than a top GPA. Candidates need not just lab skills (vacuum, etc.) but also need to know how to design and set up equipment and how to make measurements to the precision required (and how will you tell if you have). Candidate needs to be able to communicate well with others (e.g. the PI on the project) and work independently on the project. He is less concerned with hard skills than with "learning agility," which is the primary success factor (rather than knowledge). This is not just technical—a successful candidate will be able to deal with change, work with different kinds of teams (small/large, well-defined vs. nebulous goal, diverse in culture, expertise, age), and be eager to get out of her/his comfort zone. Understand the big picture of how a project fits into the broader field. Scientific and technical integrity important—an employee may need to tell customers what they don't want to hear. Employees need to be comfortable using data and statistics, and must keep on asking questions to get to the bottom of things.

8C Physicist 3: Skills that are not found in most new hires: presentation, writing, and organizational issues. Across private industry in general (not just technical sectors), 46% of new hires fail in the first 18 months. Of those failures, 12% are due to lack of technical competence, but the rest are due to lack of coachability, ability to interact well with others, ability to work with a team (what if you become the boss and your rival for that spot is still on the team?). Physics majors have no exposure to those sorts of issues.

8D Physicist 4: They are looking for specific expertise in materials science, reliability physics, experimental techniques (e.g. vacuum technology), advanced metrology/physical characterization, statistical data analysis, and modeling & simulation. A physicist in industry must learn to sell project ideas to business managers. It is important to learn about patents, trade secrets, and legal agreements. Bachelor's level hires usually know nothing about IP or patents, so they have in-house training for that. The job description for a hire at this level is usually in manufacturing, and will say EE or physics (the two are considered roughly equivalent for the purpose since nobody teaches manufacturing in academia). A candidate needs to have some lab courses and have worked with electronics/vacuum/optics. Soft skills that are needed: adaptability (is this a skill or an attitude?), eagerness to learn/try new things (is this nature or nurture?), the ability to clearly articulate your ideas to a variety of people, the ability to think on your feet (be relaxed rather than nervous) and be self-confident, willingness to work in teams and lead them ("leadership without authority") and persuade others to work with you, the ability to acquire the big picture or the company perspective (this is important in convincing management, internal and external customers, the finance division, … that your idea is good). It is important to have hands-on lab skills in operating some kind of equipment (e.g. measurement, evaporation/sputtering, other processing) and to know how to read a manual and the importance of calibration.

8E Physicist 5: Physics graduates at the bachelor's level certainly can and do become patent agents. A physics major with strong coding skills and knowledge of IP could be successful at a start-up. It also would be good to have business skills, good communication in a variety of modes (not just writing in passive voice!) to be able to write brochures etc., and knowledge of IP. More broad training (e.g. chemistry, EE) could also be valuable. Success requires a willingness to be flexible. Students should learn about the range of trajectories that careers take.

8F Physicist 6: Graduates should know at least 1 programming language such as FORTRAN, C++, Matlab, or Origin. They should have performed a measurement and data analysis using one advanced piece of equipment. If they want a job in industry, they should have had at least 1 internship at an industrial site. In industry, teams are interdisciplinary and everyone contributes their skills to solving the problem; that is they must all make an impact. Similarly, students must understand the impact of their work, particularly for any research effort they worked on. If they publish a paper, they must understand how their work affected the field as a whole; more specifically, they must understand why it was important, what skills they learned, and what challenges they overcame. Professors must make more contact with industry to learn about industrial practices and make contacts for their students. To compete with engineers for jobs, they must emphasize the strengths of the physics degree, namely problem solving and model building. Physicists are better at solving problems involving the core root physics issues and can model the effect of interest to make predictions; they can model a broader range of problems than engineers.

9 J-TUPP commissioned study of physics majors in the workforce

In order to better understand how students graduating with a physics degree are prepared to work in non-academic careers, J-TUPP commissioned an interview study of recent physics graduates and their employers. This study, conducted in early 2015 by independent evaluator Rachel Scherr, involved interviews of 14 recent graduates with physics undergraduate degrees and 5 hiring managers directly responsible for hiring these types of employees.

Most of the former physics majors had graduated 1-5 years earlier, and all had been hired into positions in industry, technology, business, and the military. Former physics majors reported that useful disciplinary knowledge included electronics, electricity, and magnetism. Many mentioned the importance of problem solving, which appeared to have varied meanings. Some discussed it as the ability to break down a complex problem into simpler, solvable problems, and some associated it with the ability to learn about new topics. Several participants specifically reported that their experiences researching, teaching, and programming were important preparation for their current positions.

Former physics majors also identified areas where they wished they had learned more before entering the workforce. In particular, they desired more programming skills and more experience in industrial and applied physics environments. Programming was almost unanimously characterized as highly desirable. In addition, former physics majors felt that learning more about how to characterize the marketable skills acquired during their degree would have helped them.

Hiring managers were individuals who made the hiring decisions to bring a person with a physics major into the organization. They value physics majors for their broad training, technical and instrumental proficiency, and ability to solve ill-defined problems. When asked to identify skills that would make physics majors more appealing, hiring managers asked for increased experience with research, more practice working with teams, and improved abilities to communicate verbally.

To help prepare majors for non-academic careers, hiring managers encouraged physics departments to facilitate connections between companies and students, and to involve students in research early in their education through lab groups and internships. Students were encouraged to take advantage of internship and teaching opportunities, to learn about a variety of career opportunities, and to develop excellent writing skills.

It may be particularly important to note the areas where former physics majors and hiring managers agreed on limitations in the physics degree education. Both groups advocated for physics majors to gain more research and industry experience, programming skills, and knowledge of the marketability of the skills in the degree.

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