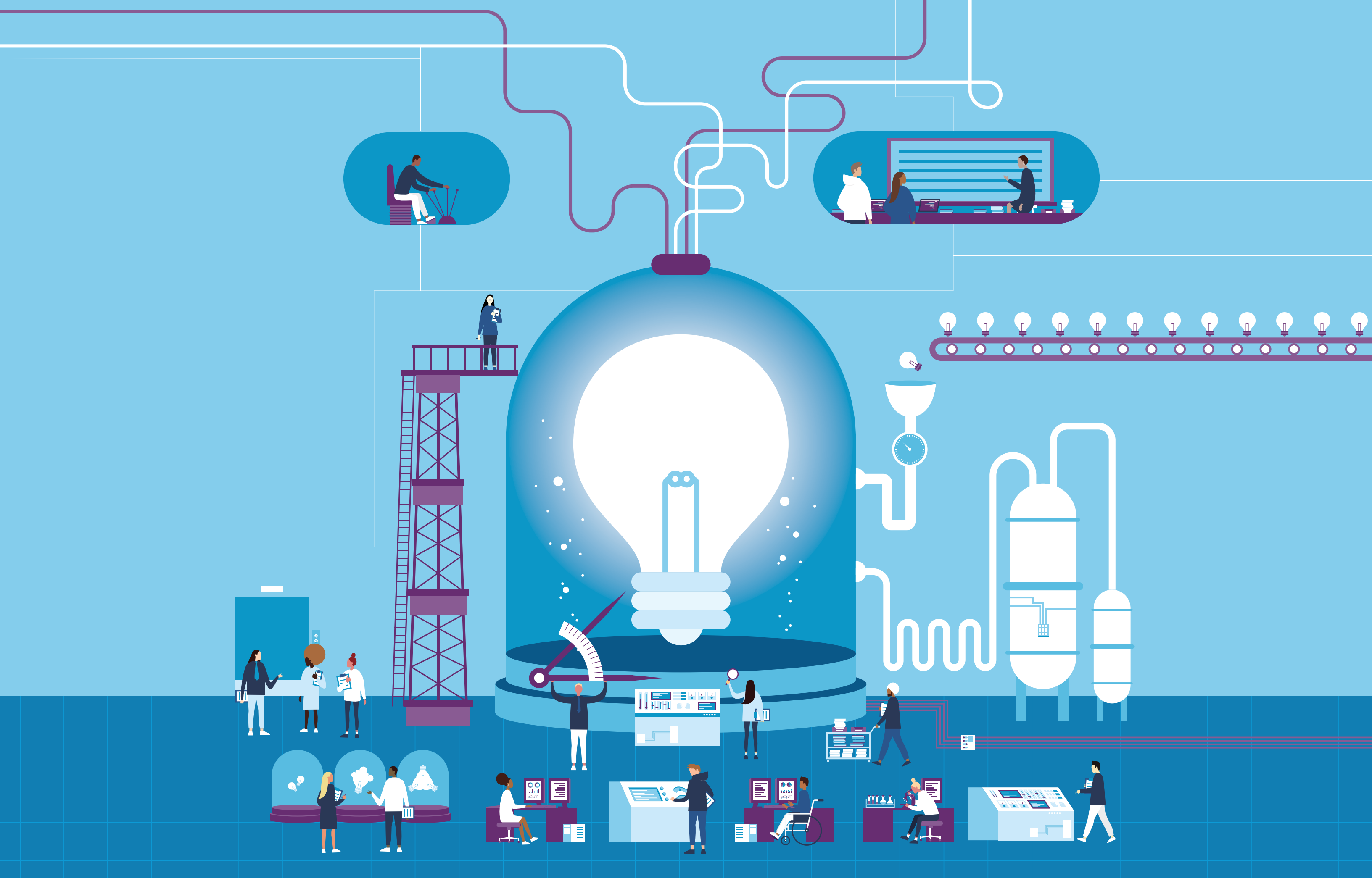
EPIC

Educating Physicists for Impactful Careers

Equipping Physics Students to Change the World Through Physics Innovation and Entrepreneurship Education



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APS physics | PIPELINE

About the EPIC Report

This report is a product of the PIPELINE Network project, led by the American Physical Society in partnership with Carthage College, College of William and Mary, Rochester Institute of Technology, University of Colorado Denver, George Washington University, Loyola University Maryland, Wright State University, and Worcester Polytechnic Institute and funded by the National Science Foundation under grant number 1624882. The authors of this report wish to thank the participating faculty from the partner institutions for their input, as well as the reviewers of this report, who have helped to make it a valuable resource for the physics community.

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About the PIPELINE Network

The PIPELINE Network is a three-year project bringing together the efforts of seven institutions to create and document new approaches to teaching innovation and entrepreneurship in physics.

The project is charged with developing research instruments to investigate the link between physics innovation and entrepreneurship (PIE) education experiences and corresponding student and faculty attitudes. These deliverables will be made available via the web, email, and meetings.

The project is advised by an industry team and by three institutions with strong innovation- and entrepreneurship-focused physics programs: Carthage College, Case Western Reserve University, and Kettering University.

About the American Physical Society

The American Physical Society (APS) is a nonprofit membership organization working to advance and diffuse the knowledge of physics through its outstanding research journals, scientific meetings, and education, outreach, advocacy, and international activities. APS represents over 55,000 members, including physicists in academia, national laboratories, and industry in the United States and throughout the world.

Authorship

The American Physical Society has sole responsibility for the contents of this report and the questions, findings, and recommendations within.

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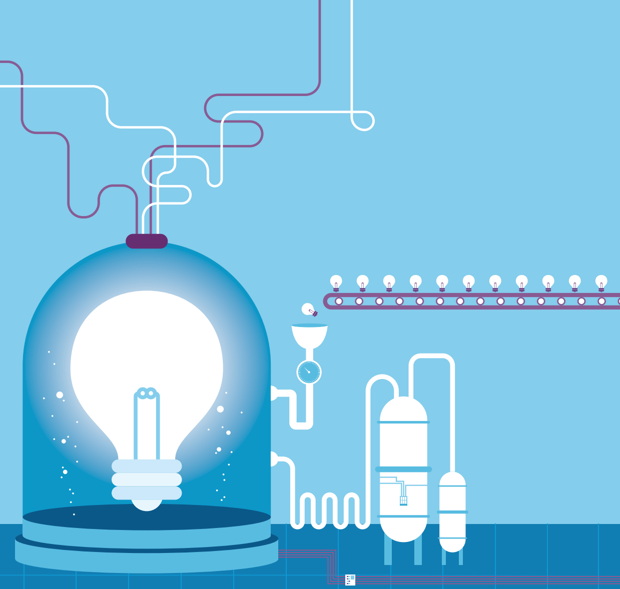
Executive Summary



For Faculty and Administrators

- Physics innovation and entrepreneurship (PIE) education better prepares students for 21st century careers.
- PIE education makes the discipline more attractive to potential students, sustaining and increasing enrollments.
- PIE connects physics and social impact that is attractive to students and prepares them to leverage their physics training in diverse careers, without reducing the physics content delivered to students.
- The PIPELINE* project developed and makes available tested approaches to incorporate PIE in the student experience.
- PIPELINE* has identified barriers to PIE implementation among physics students and faculty and has recommended actions to address these concerns and support successful implementation of PIE.
- Academic institutions can leverage their alumni networks, regional businesses, economic development organizations, and other regional development organizations.

For Funders, Professional Societies, and Industry

- PIE supports the strategic goals of societies and industry and increases the impact of physics education.
- Academic research should expand to include projects with commercial applications and industry partnerships.
- Funding agencies should support research that includes industry partnerships and/or involves commercial applications.
- PIE should be broadly disseminated across academic departments and promoted by professional societies through publications, conferences, and media.
- Companies should actively engage with physics education, including participating in courses and projects, contributing to faculty development, and providing opportunities for student engagement.

** Pathways to Innovation & Physics Entrepreneurship: Launching Institutional Engagement (PIPELINE) Project*

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Introduction and Overview

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Preparing Students for the 21st Century

Many factors need to be considered as we educate physics students for the roles they will fill in the 21st century: new and challenging world problems to solve, job flexibility, multiple employers, a gig economy, new demographics in the US, and international competition for everything. Physics education is one of the best ways we can prepare them—and when we adapt and improve it to incorporate elements of innovation and entrepreneurship, we arm our graduates with the best tools to be successful in the world ahead.

This report is an outcome of the ***Pathways to Innovation & Physics Entrepreneurship: Launching Institutional Engagement (PIPELINE)*** project. It discusses what was accomplished and learned and presents ways that innovation and entrepreneurship education can be incorporated into the undergraduate experience of your students to better prepare them for the 21st century. PIPELINE team members, shown in **FIGURE 1**, worked together to develop methods to incorporate Innovation and Entrepreneurship (I&E) into the experience of physics students, build a network of practitioners, and promote I&E within the physics community. Innovation and entrepreneurship encompasses problem solving in situations of uncertainty, creativity and design thinking, incorporating human factors (e.g., need, desirability), opportunity recognition, managing projects and diverse teams under constrained resources, a multidisciplinary and flexible approach to problem solving, learning and applying new technical skills, and communicating with diverse and nontechnical audiences, among others. I&E encompasses a "sociotechnical" way of thinking. All of this work is aimed at preparing students for the professional and career challenges they will face in the 21st century, making physics a discipline attractive to students, and preparing students to apply physics in more diverse ways to successfully address real-world problems.

A Bit of History

I&E has been incorporated into a number of education disciplines over the last 25 years or so but has not been broadly utilized in physics. At the same time, employers have indicated that while physics graduates are valuable, they lack some of the key skills and abilities that would greatly improve their performance in the workplace and are provided by I&E education. The PIPELINE project was an eventual outcome of a meeting of I&E-minded individuals who participated in an invited session at the 2012 APS March Meeting in Boston intended to introduce I&E to the physics community. Noting the great potential value of physics combined with I&E education—***Physics Innovation and Entrepreneurship (PIE)***—these individuals identified a number of steps to help transform physics education:

- Publishing articles in *Physics Today* and *APS News* on PIE [1, 2, 3] to introduce and promote PIE
- Building a partnership with VentureWell, the leading organization in innovation and entrepreneurship education in science and technology (www.venturewell.org)
- Holding a workshop on PIE education (held June 2014 in College Park, Maryland) [4]
- Incorporating a PIE workshop into the American Association of Physics Teachers (AAPT)/APS Department Chairs Conference (held June 2018 at the American Center for Physics)
- Offering special sessions at APS meetings, which were held at March and April meetings through 2019
- Creating communication structures to build a community of practice
- Submitting a grant proposal to the National Science Foundation to provide the resources to create PIE materials, research student and faculty attitudes and experiences in I&E education, and create a network that would become a community of practice and practitioners of PIE

The last of these elements resulted in the creation of PIPELINE. The project succeeded in accomplishing its goals, including creation of a website (www.aps.org/programs/education/innovation/pipeline/), a newsletter, a library of implementation methods [5], site visits to campuses across the country, numerous sessions at APS and AAPT meetings, and participation in and presentations at VentureWell's OPEN conferences.

PIPELINE also benefited from other efforts aimed at transforming undergraduate education happening in the physics community. The most significant of these was the Joint Task Force on Undergraduate Physics Programs (J-TUPP), which studied and published the Phys21 report on the demands and expectations of physics programs for career success in the 21st century [6, 7]. The educational elements developed in PIPELINE all contribute to, and are in support of, Phys21 recommendations.

FIGURE 1: PIPELINE Team Members

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How to Use This Report

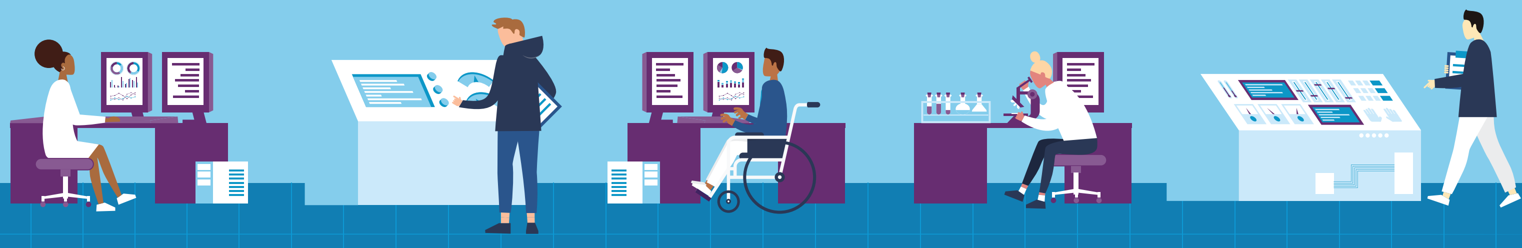
It is our hope that this report will motivate the physics community to incorporate PIE as a core component of physics education. Bringing I&E elements, such as nontechnical communication skills, project management, and industrial physics applications, into the student experience is new and challenging for most academic environments—especially in physics. We recognize that many barriers seem to make this appear difficult. First and foremost is the perception among faculty that adding PIE elements to the undergraduate physics curriculum means taking other physics out. That is not the case. What PIPELINE has developed does not reduce the physics that students learn—in fact, it enhances it. In this report you will find a variety of low-risk and low-cost approaches to bring I&E to your students, promote I&E within departments and to administrators, and enhance physics education and the research enterprise. This report also includes information that will influence the professional societies in which we participate, as well as recommendations for funders and other agencies with whom we interact.

A Note About COVID-19

At the time that this report was being prepared, the COVID-19 pandemic had begun to seriously impact all aspects of life, including higher education. Those impacts will pose challenges to the implementation of the work reported here but may also provide new and unique opportunities to experiment with the recommendations made. For example, increased use of virtual tools may make it easier to bring in outside speakers to online classrooms; more students may have access to activities through online learning. Other pedagogical approaches, such as hands-on laboratory activities, may be more difficult and necessitate redevelopment. What is almost certainly true is that now, more than ever, universities will need to demonstrate that they are providing students with the skills, knowledge, and mindset for finding innovative solutions to difficult, far-reaching problems. We hope that the approaches described in this report serve to inspire educators who are adapting to the post-COVID environment to add these new curricular elements to the educational landscape they currently inhabit. We also hope that this report will strengthen the resolve of funding agencies to support innovative approaches to teaching that will culminate in student outcomes that better prepare them for the diverse career paths that they will pursue and allow them to impact and address the many major issues facing 21st century society and the world.

Why Now, and Why This?

2



Academia at a Crossroads

Every industry has cycles, and higher education isn't immune. New threats have accelerated change—and today we face a rapidly changing educational landscape. Some of these are driven by fundamental changes in education and technology, whereas others are driven by major world events, such as COVID-19. Among the many factors, higher education is expected to prepare students for careers that will likely involve multiple positions in varying disciplines over several years. The incoming high school population is savvy regarding the costs and potential returns of education, placing demands on higher education to deliver those returns. Over the last several decades there has been substantial growth in tuition and room and board costs, which many are unwilling or unable to pay. As a consequence of these and other influences, higher education is under pressure, as evidenced by the closing and restructuring of institutions across the country. In the last four years, 92 nonprofit colleges and universities have either closed or merged, and more than 100 for-profit institutions are no longer in operation [8]. Institutions of all sizes and types—from small liberal arts campuses to state universities—have been impacted. COVID-19 has resulted in suspension of on-campus activities at many institutions, and potential changes in tuition and room and board cost structures are significantly impacting the financial health of many colleges and universities. I&E education has the potential to create greater value for students as it better connects the academic discipline to career success. This value proposition is important for colleges and universities to offer to prospective students and their parents as they decide where, or whether, to enroll and may be an important factor in recruiting and retaining students, which can help sustain the financial health of the institution.

There are also international pressures. Academic institutions are depending on recruiting students from new markets, and international economic competition is driving education in other countries to improve and adapt as these nations strive to achieve economic success. Recent worldwide medical crises point to the potential reduction in the pool of foreign students and apply greater pressure on other nations to become more economically independent. Sustaining economic competitiveness for the United States and remaining at the forefront of undergraduate and graduate education demand that education here adapt to better prepare students for these new challenges. And, of course, the students benefit as well from this preparation.

Demonstrating value and adapting to the new demands that education must meet are critical to the success of academic institutions. Indeed, the same can be said for individual departments and disciplines, including physics, as each must draw a substantial audience to justify its continued operation within an institution. Although various I&E–focused disciplines, institutions, and initiatives have been launched worldwide, physics is uniquely positioned to become a leader in the transformation of student development and preparation for the future [7]. Physicists are at the core of the development of new and fundamental technologies and have broad understanding and capability, allowing them to create, manage, and oversee complex science and technology projects.

Student (and Family) Expectations for Meaningful, Well-Paying Employment

According to the National Center for Education Statistics, the total number of students in grades 9-12 rose nearly 20% from 1999 to 2016 and is projected to remain nearly flat over the next decade [9] and fall substantially starting in 2026. The ethnic makeup of this group also shows something else: The number of white students is declining, while enrollment among Black students remains level, and the number of Hispanic/Latinx students has doubled from 1999 to 2016 and is expected to increase by nearly 50% over the next decade. Many of these students will be the first generation to attend colleges or universities [10]; their decisions about which major to choose may be strongly influenced by parents and family members, many of whom see a well-paying job and having a positive impact on their community as key desired outcomes of a college degree. In physics, students from underrepresented groups make up a tiny fraction of degrees awarded [11]. If physics is to become an attractive option for future students, it must fulfill these expectations for meaningful employment. The current poor performance of physics in demonstrating or delivering these outcomes to prospective students does not bode well for the discipline.

PIPELINE conducted a study of student perceptions of physics as a discipline, their career goals, and their perceptions about the role of innovation and entrepreneurship in physics education. These data shed light on the issues and challenges faced in recruiting majors. When asked to describe being a physics major to high school students considering physics, physics majors frequently described the importance of understanding how the universe works, developing a useful skill set, and being smart and good at physics **(FIGURE 2 ON PAGE 9)** [12]. In contrast, students rarely described doing physics as a means to solve problems that help people, communities, or the world. Even more, a subset of male students stated that social impact was not important for physics, as the ideas had sufficient value in their own right regardless of their application, though all female respondents said social impact was somewhat or very important **(FIGURE 3 ON PAGE 10)** [13]. However, when physics majors described their "dream job," many physics majors in our study hoped their careers would address problems that make a positive difference in their world [14].

So we see a disconnect where part of a student's larger identity as a person is wanting to do good in the world while physics programs generally do not embrace that same value. Many students enter and persist in physics, but we are likely missing many capable and passionate students who are less likely to consider physics because it seems aloof. The data suggest physics educators already do an excellent job portraying physics as a discipline motivated by curiosity and scientific inquiry; however, there is room for improvement in showing students how physics knowledge can help improve our society and the world around us.

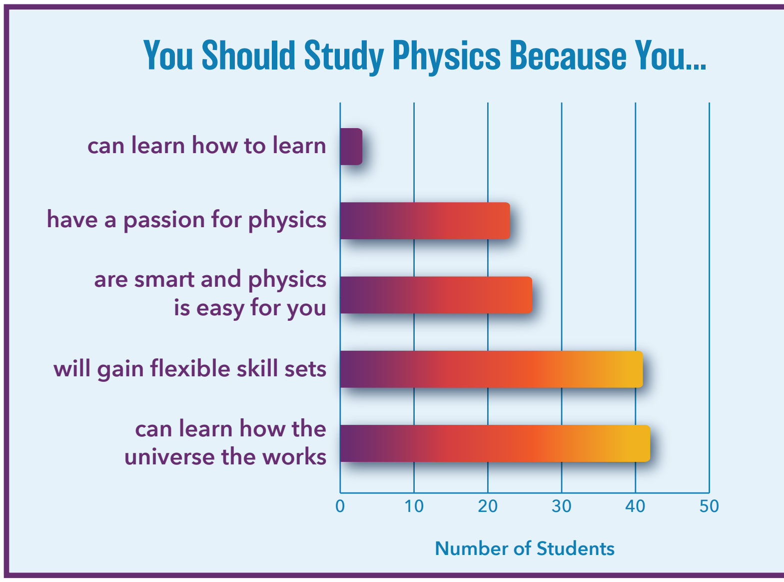


FIGURE 2: What Physics Majors Say

Of 178 physics majors given a set of reasons that they would recommend physics to a prospective major, most selected understanding the universe or gaining skills.

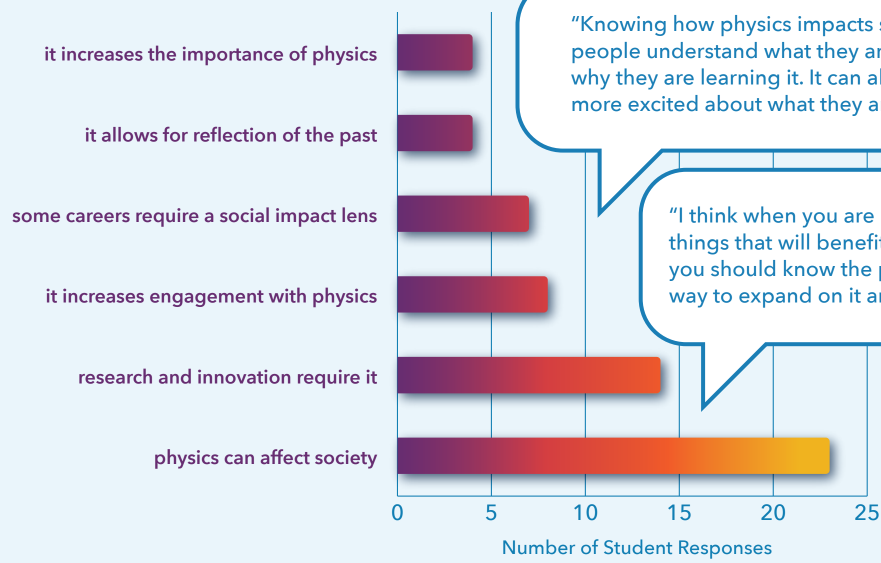
Source: Leak et al. [12]

This perception of physics as a discipline contrasts with the needs and interests of incoming college students, who are often attracted to disciplines that they can clearly connect to jobs that pay well and have an impact on their communities and the world. This mismatch of perception and reality is a challenge that physics needs to meet if it will be positioned to attract and retain majors. Other disciplines have consciously addressed these perceptions. Engineering is seen as a discipline that connects students with a clear career outcome that can have direct social impact and is successfully recruiting a far larger number of underrepresented minority students **(FIGURE 4 ON PAGE 11)** [15, 16]. *Physics could be viewed this way, too*. Ninety-five percent of physics students are ultimately employed in diverse industries and are even better prepared to utilize their broad science understanding and problem-solving skills to address real-world issues than engineers (and are recognized to do so). It is therefore unfortunate that physics is often perceived as a discipline leading to limited career

FIGURE 3: Social Impact

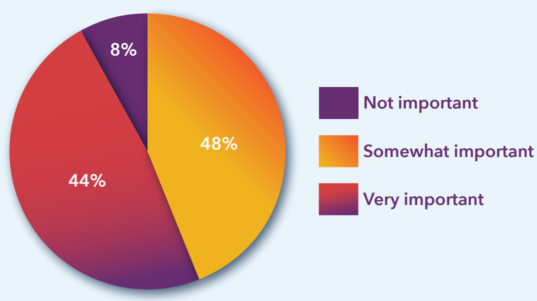
Students' perspectives on the importance of social impact within physics education.

Social Impact Is Important Because...



"Knowing how physics impacts society will help people understand what they are learning, and why they are learning it. It can also get students more excited about what they are learning."

"I think when you are building different things that will benefit us as a society you should know the physics of it as a way to expand on it and make it better."



When asked about the importance of social impact of physics, 48% of surveyed majors said very important, and 44% said somewhat important. All female students said social impact was very or somewhat important.

Social Impact Isn't Important Because...

Of the five students who believed social impact to be not important for the physics discipline, the reason given was social impact wasn't necessary for many aspects of doing physics.

In these responses physics was typically described as a discipline that "can just be fiddling with equations and abstract concepts."

"Knowledge for the sake of knowledge is a valid goal on its own, and while it is obviously good to benefit society it is not a necessity.

You do not have to think about the impact on some random person in Australia while you study the collision of protons."

Source: Williamson et al. [13]

FIGURE 4: Engineering and Physics Bachelor's Degrees Received by Underrepresented Minority Groups in 2016

A larger proportion of engineering bachelor's is awarded to underrepresented minority students compared to physics bachelor's. Although these percentage differences are small, they amount to a large difference in the number of students in each field.

		Number of Degrees Received	Percentage of Total Degrees
Hispanic Students	Engineering Bachelor's	11,301	10.7%
	Physics Bachelor's	715	9%
Black Students	Engineering Bachelor's	4,166	3.9%
	Physics Bachelor's	251	3%

Source: Anderson et al. [15], www.aps.org/programs/education/statistics [16]

options, primarily academic research careers focused on fundamental topics with little connection to human needs. These perceptions dissuade otherwise interested students from pursuing it as a major.

At the same time, employers say that physics graduates—as valuable as they are—are not well prepared in key areas that ultimately hold them back compared to other hires [17]. A survey was conducted at Kettering University of industry employers who worked with physics students over the course of a semester-long industry internship required under their program. The surveyed employers stated that the physics students were competent in some key scientific and technological areas and were strong at continued learning; it also indicated that physics students lacked key skills, knowledge, and mindset to be successful in private sector environments **(FIGURE 5 ON PAGE 12)** [18, 19]. Evidence shows that physics programs that have addressed these topics have had greater success in recruiting students and placing them in jobs and careers [6].

FIGURE 5: What Employers Say

Industry employers who participated in a survey conducted at Kettering University (155 respondents) and a national APS workshop on issues facing industry indicated that although physics students tend to be competent in some scientific and technological areas, they lack other key skills, knowledge, and mindset to be successful in private sector environments.

More than 80% of surveyed employers agreed that physics majors

- Could easily grasp new knowledge and concepts
- Were able to identify, formulate, and solve problems
- Were able to 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

Employers also said that physics graduates are missing important training and experience

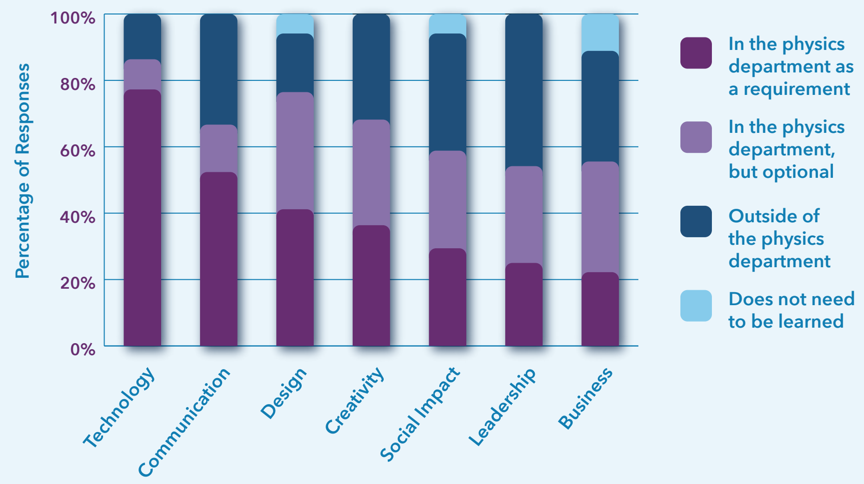
- Ability to design a system, component, or process to meet a specific need
- Ability to function on multi-disciplinary teams
- Ability to recognize value of diverse relationships (customers, supervisors, etc.)
- Leadership skills
- Familiarity with basic business concepts (i.e., cost-benefit analysis, intellectual property, project management)
- Communication skills (oral and written), especially how to tailor a message to an audience

Source: Roughani and Svinarich [18], Rumble et al. [19]

Other research on current physics students indicates that they (a) do not recognize the importance of these skills or (b) do not believe that a physics education should provide them **(FIGURE 6 ON PAGE 13)**. If physics students do not recognize the potential impact of their abilities on real-world problems, they do not recognize the positive impact they could be having. If this attitude can be changed—and the skills and abilities of PIE brought to the table—not only will students be well prepared for their careers, but physics will also be attractive to the diverse population of incoming students who currently flock to other disciplines. Physics, reimagined as PIE, can be extremely impactful, specifically because of the breadth of technical expertise that physics offers. Section 3 of this report provides guidance as to how this can be accomplished.

FIGURE 6: Where Students Feel I&E Aspects Should Be Learned

Research shows that many physics students do not believe that physics classes should teach communication, business, or innovation and entrepreneurial skills [12].



Source: Leak et al. [12]

The Impact of I&E Education on Academia

Why should academia, in particular academic administrators, want to see innovation and entrepreneurship built into their programs? For one thing, recruiting and retaining incoming students, with their diverse backgrounds and changing demographics and expectations for employment and financial return, are critical for the viability of academic institutions. Students today want and demand educational experiences that are engaging and connect to the real world. This is true at each level—for the institution as a whole, for an individual college or school, and for each department or program. Physics has faced this type of challenge before: In the early 90s physics suffered an enrollment crisis that led to a greater sense of urgency for reforming physics instruction, such as adopting methods based on physics education research [20]. Today, implementing PIE can help buffer the enrollment issues of the 21st century.

Physics has traditionally funded its research enterprise through grants. Competition for those funds has increased, and the likelihood for continued support from the same agencies has dwindled [21, 22]. There are many interesting, meaningful, and lucrative research projects out there—some that come from industry and others that apply physics to significant world problems that are fundable and are of interest to the next generation of student researchers. PIE lends itself to solving these problems and attracting the associated funding, expanding the landscape of research dollars available to those in academic programs.

The Impact of I&E Education on Professional Societies and Economic Development

Professional physics societies—APS, AAPT, Society of Physics Students (SPS), and others—all have goals to prepare the next generation of scientists, promote physics as a discipline, and engage physicists with improving the world. As we detail in Section 4, promoting PIE education to their membership and to the communities that they influence will help societies contribute to meeting all of those needs. PIE makes physics a more attractive discipline, helps recruit more physics-trained individuals to apply their skills where they can contribute to the world, and gives them the tools to do so effectively.

Economic development will be enhanced by a workforce that has not only the unique capabilities that physicists bring to the table but also the background and skills to be productive in work environments, commercialize technology more rapidly and cost-effectively, and reduce training costs for organizations. Traditional funders of physics and physics research will also benefit, as the long-term value of physics research will be better understood and students will be more attracted to the discipline. With a wider, more diverse cadre of physics practitioners and with greater likelihood of successful research commercialization, funders will more easily justify their budgets.

The Impact of I&E Education on the World at Large

Can you name a technology that didn't start in physics or where physics doesn't broadly and deeply apply? Can you name a problem facing the world that wouldn't benefit from the application of physics and the input of physicists? If physics is perceived as the vital source of technological discovery that it truly is and, indeed, prepares its graduates to more efficiently develop answers to real-world problems, many new and effective solutions will be found. Energy, the environment, health, safety, food, and water are all topics that physicists can address. The potential benefits of physics to the world are immense, and in a mutually beneficial arrangement, the perception that physics can deliver those benefits will draw more students, especially women and underrepresented groups, who could contribute so much to the world if given the chance.

Physics Departments and Faculty Can Do This—But How?

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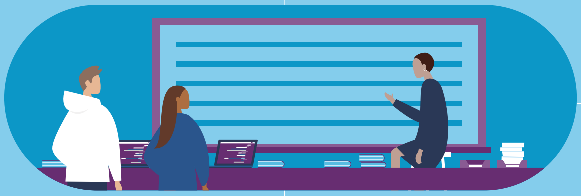


Overview: Incorporating I&E Into the Student Experience

It may seem daunting to think about building innovation and entrepreneurship into the physics curriculum. But there are important considerations that make this not only possible but easier than it seems. The goal of education is to achieve desired outcomes for students over the course of their education—and those outcomes can be achieved in different ways at different times and not all in one place. For example, students can achieve certain outcomes by successfully completing formal classes, some outcomes are achieved by completing internships or research experiences, and other outcomes can be achieved by attending conferences or other activities or offerings.

The optimal process is to identify and utilize the resources and assets that are available across your campus and in your community so that each student has the experiences over the course of their education to achieve those desired outcomes, which may or may not have to come from the physics department itself [23]. Some of the skills, knowledge, and attitudes can be well delivered to students by enrolling them in courses from across your campus through appropriate advising. Others can be delivered through extracurricular experiences, as we will discuss below. Most importantly, there are ways to connect the physics you are teaching to innovation and entrepreneurship learning outcomes that do not in any way dilute the physics itself. These methods adapt *how* physics is taught to ensure that the core physics skills that make graduates so successful are not depleted, but enhanced. These types of experiences also provide students opportunities to apply the physics they learn, which can help them to achieve higher levels of learning. Encouraging students to utilize and apply the physics they learn to real-world situations helps students appreciate the relevance of what they are learning, which also promotes long-term learning.

This section gives you example tools and methods for incorporating I&E education into the experience of your students. As the PIPELINE team developed these approaches, a research study on faculty attitudes was conducted to identify the barriers you feel or may encounter in doing so and how to overcome them. Some of the outcomes of that study are noteworthy and are summarized in **FIGURE 7**.

FIGURE 7: Faculty Views of PIE

Response	Are you aware of PIE?
Yes	53%
Not sure	35%
No	15%

Themes from faculty survey regarding implementation of PIE

1. **Lack of knowledge about nonacademic careers** limits faculty's ability to develop and deliver PIE-related curricula.
2. **Lack of recognition for faculty** who integrate PIE and career-focused elements into their teaching reduced motivation.
3. **Lack of interest among colleagues** and, more broadly, their departments left PIE champions feeling isolated.
4. **The physics major is already full**, leaving little room for new topics, such as PIE.
5. **Resources were lacking**, including connections to alumni who work in private sector, time and funding to develop and implement PIE, and curricular materials.

Source: Bailey and Arion [3]

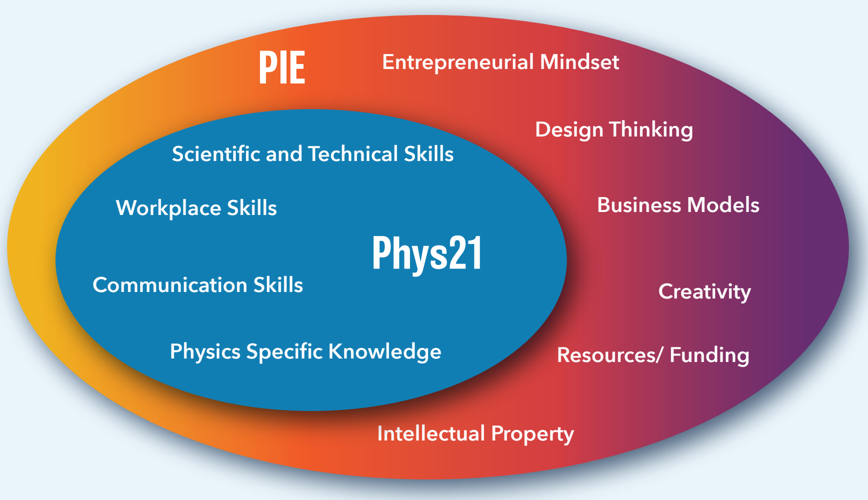
For example, a significant fraction of faculty express that preparing students for nonacademic careers has merit, but when asked how well they're doing it, one-half think they're doing it well, and the other half think they're doing it poorly. Many faculty report that they aren't capable of preparing students because of their own lack of knowledge about nonacademic careers and that lack of interest in their departments and the dearth of recognition for I&E education are impediments to those who wish to take this on. It is important for faculty to recognize that there are experts on campus who can help them overcome these barriers. For example, scheduling time to meet with colleagues working in the career services or the alumni office may be helpful for understanding the types of positions physics graduates secure after graduation. Making connections with alumni can provide faculty insight into the skills that physics graduates use as well as the areas in which they wish they had more education. Most colleges and universities already collect information from graduates. Physics faculty can tap into this resource. And if the input from industry discussed earlier is a guide, physics departments really aren't successfully preparing their students for nonacademic employment. Addressing these issues is critical for the survival of programs and departments and for recruiting and placing students in the 21st century landscape. Section 4 of this report will give you tools to overcome these issues as you pursue PIE education outcomes for your students.

Using What PIPELINE Developed

One of the goals of PIPELINE has been to prototype tools and methods for incorporating I&E components into the physics curriculum. We chose to categorize our efforts according to the epistemology documented in the Phys21 report of the J-TUPP project **(FIGURE 8)** [6, 7].

FIGURE 8: The Scope of PIE Related to the Recommendations of Phys21

A representation of how learning areas included in PIE overlap with recommendations from the Phys21 report. PIE includes workplace-relevant skills, scientific and technical skills, physics-specific knowledge, and communication skills but also includes additional skills and knowledge relevant to innovation, entrepreneurship, and private sector employment.



Source: Bailey and Arion [3]

There are numerous ways to categorize outcomes, but these, tied to extensive research by the J-TUPP panel and incorporating input from all of the affected constituencies, are an excellent baseline from which to begin. They address the educational outcomes that students need for career success. The first category, physics-specific knowledge, addresses the areas with which we are all most familiar, with adaptations to make that content more directly relevant to student needs in the working world. The second category, scientific and technical skills, in part, is responsible for the immense success of physics graduates in many careers, as they obtain broad capabilities in many technical areas, as well as the analytical, numerical, and experimental abilities that they apply to solving problems. The third area, workplace-relevant skills, is a direct outcome of the demands of the workplace on new hires and for the long-term success of students in their careers. The last category addresses a range of communication skills, including the typical areas addressed in physics education such as technical talks and research paper writing, but expanded to include communicating with nontechnical audiences and the communication needs demanded in industry. The activities developed in PIPELINE were conceived and implemented with these outcomes as their primary goals.

There Are Options

There is no one "right way" to bring PIE to students. There are many ways, and the variety of choices makes it possible for you to develop implementations that suit your particular institution, department, student needs and expectations, and campus and community resources. In the post-COVID-19 environment, online learning approaches and asynchronous teaching open up new modalities to interact with students. Some of the approaches discussed below are easily adapted to these kinds of teaching methods and are so noted; others don't necessarily translate easily. None of the approaches in any way diminishes the core physics that we need students to experience and learn. Rather, they enhance that experience in ways that make physics more relevant to the jobs and careers students are likely to pursue, expand the student knowledge and skill base to address the expectations that employers tell us they have for incoming hires, and give them the skills to become even more powerful innovators, ready to tackle the world's challenges.

Within the physics-specific skills category, the approach is to adapt the teaching methods, examples, and student experiences to more closely align the physics to real-world situations and applications. This adaptation can be accomplished by updating laboratory exercises and experiences to utilize modern tools; for example, having students use free 3D CAD software to draw their experimental setups gives them the modeling experience industry wants them to have without changing their exposure to physics content. Teaching physics in the context of a commercial application—such as the Hyperloop discussed below—allows students to understand fundamental physics while also absorbing the concepts of uncertainty, technical feasibility, and human desirability. Having students do projects that connect their physics learning to applications can enhance their experience without taking up class time. For example, advanced physics students could study and report on the operation of ring laser gyros as general relativity-based technologies for inertial guidance systems [24]. Nearly every element in physics education can be easily adapted to connect learning to I&E student outcomes. All of these can be accomplished in class or using online or asynchronous teaching methods.

When it comes to some of the nontraditional topics that I&E education incorporates, remember that you don't have to deliver it all yourself. As you consider some of the content areas that may be removed from your personal realm of expertise, you may not feel prepared to deliver these educational components to students. Across your campus and in your community is a plethora of assets on which you can draw to bring students the kinds of experiences that will prepare them for their futures. For example, one of the expected skill sets is experience with a variety of laboratory and manufacturing equipment and software. Since physics labs are equipped with fundamental measuring instruments (scopes, meters, etc.), one could work with a chemistry department so students can see NMR/MRI, UV and IR spectrometers, mass spectrometers, and other types of equipment that are likely to be found in industry environments. Similarly, CNC and CAD systems are likely available in either an engineering department or a local/regional business. In the post-COVID-19 environment, some of these goals could be accomplished by having students visit regional businesses or by having industry experts engage students online with demonstrations of equipment and industry methods. Even YouTube videos can be used to instruct students in the use of industry standard equipment.

Workshops on project management skills, for example, are sometimes offered for free (or at low cost) by regional economic groups, such as small business development centers (SBDCs) or economic development corporations (EDCs)—some of which could very well be offered online. These types of organizations also host seminars or speaker series that can be attended by students and faculty. You can also invite them to speak with your students directly—either in person or virtually. Attorneys will often give free talks to faculty and students on intellectual property. Taking part in activities like these also provides an opportunity for you to osmotically learn skills that will enhance your knowledge and experience and provide benefit to you and your students in the future.

Examples of PIE in Physics Education

The PIPELINE resource library [5] contains a few examples of pedagogy developed and tested by project partners. The content of the library is a first step in the creation of a fully developed curriculum, which is a future project and which will benefit from input from the broad physics community. The materials presented here can be used in your courses and programs—and the contributors are happy to work with you, including site visits, to flesh out details and make their creations useful in your programs. These are presented as a sample of how physics education can add PIE to the student experience without losing what makes physics *physics*.

Teaching Physics Using Real-World Applications: The Hyperloop*

Imagine you're designing an ultrahigh-speed train that will travel the East Coast of the US. How quickly can it accelerate from a stop to full speed, and what's the tightest-radius turn it could achieve while remaining comfortable for passengers? How long would the trip from Boston to Washington take, given those constraints and the distances, masses, and energy requirements? This kind of problem lets you teach core elements of kinematics—1D motion, accelerated motion, circular motion, energy conservation—and introduces the human factors and real-life considerations that arise in the solution of real-world problems. It requires both "exact" calculations and effective estimation skills—key skills needed in real-world employment. This pedagogical approach can be applied at various levels in the student experience and utilized as a scaffold on which a semester course can be built. Developed and prototyped at Loyola University Maryland (LMU), the Hyperloop materials are available on the PIPELINE website [25].

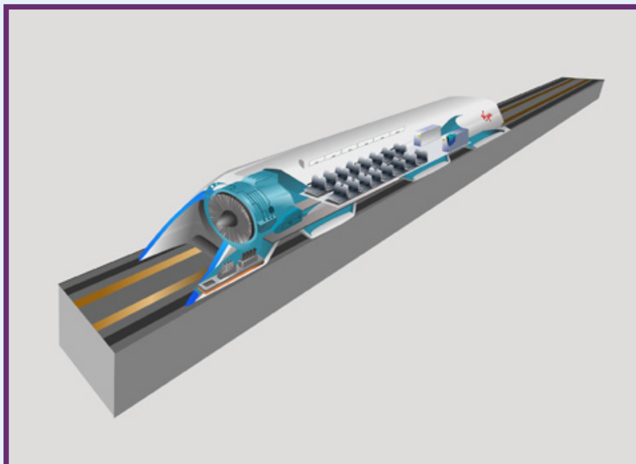


FIGURE 9: LUM - Hyperloop Module for Teaching Introductory Physics*

A prototype for the Hyperloop, a train that is designed to travel at speeds greater than 700 km/hr in evacuated tubes. The Hyperloop introductory physics module developed at Loyola University Maryland is built around this concept and includes questions of technical feasibility and human desirability, in addition to physics.

*Can be easily adapted to online learning environments.

Entryways to Add Content to the Student Academic Experience: Pop-ups*

Sometimes there's a skill or content area you want your students to have, but it doesn't represent a full course's worth of material. Or, it's an as-you-need-it skill to apply to a particular project or situation. Already utilized in several disciplines, the *pop-up course* is just as applicable to physics education [26]. The Rochester Institute of Technology (RIT) has prototyped a number of pop-ups that bring skills to students. Need your students to gain basic electronic assembly skills? Build Arduino-based projects? Learn a 3D CAD program? A short, one- to few-day experience may be all you need to achieve the learning goals. Taught outside of the "usual" course structure, pop-ups let you enhance student learning without, necessarily, complicating course scheduling and teaching loads [27, 28, 29].

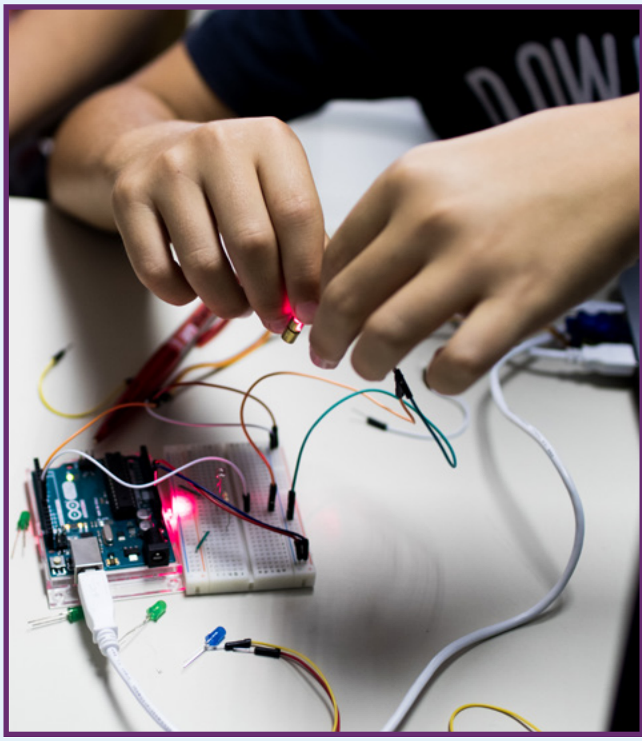


FIGURE 10: RIT - Pop-Up Course on Arduinos*

Arduinos are an extremely powerful and versatile way for students to create hardware-based solutions to problems. Arduino pop-up courses developed at the Rochester Institute of Technology teach students important hardware- and software-related skills.

*Depending on the topic or skill being covered, online or asynchronous approaches may be suitable for Pop-ups.

Bringing Hands-on Lab Skills Back into the Curriculum: Technical Competencies

One of the outcomes of the J-TUPP study, documented in the Phys21 report, is the need for students to have hands-on experience with a variety of equipment and technologies, so that they are able to employ technologies utilized in industry [30]. As described earlier, one of the ways to achieve this is to utilize facilities across your campus and in regional industries, and another is to build up a stash of equipment that students can utilize to gain experience. The University of Colorado Denver (CU) has created an environment in which students can engage with a wide span of technology—from macro to micro/nano, optical to radio, mechanical to optical to electronic—and has begun the development of a library of technical competencies that faculty and students can draw upon to gain the broad hardware experience that industry demands. Local high school students were also recruited to participate in the program and were mentored by undergraduate participants [31].

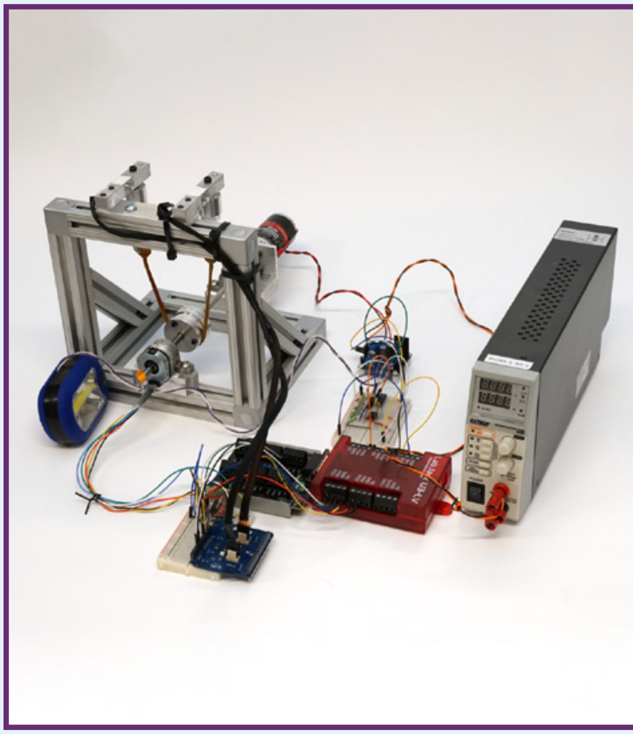


FIGURE 11: CU Denver - Prony Brake Experiment

A grand finale experiment for the Applied Physics labs for first-year physics majors at CU Denver related to specific technical competencies learned through the year. The apparatus measures the speed of a permanent-magnet DC motor in response to change in frictional torque.

Incorporating Project Management Into the Physics Curriculum: Agile Project Management

It would be great if every project we undertook had unlimited resources and time in which to complete it. It's never like that. So how can students gain basic project management experience that is crucial in real-world environments? The College of William and Mary prototyped an agile project management exercise built around student teams building a CubeSat mock-up—on a resource-constrained and time-limited basis. In the activity, students set roles within their group, prioritized activities, allocated resources, and met mission guidelines—all at the same time. Materials for this activity are available at [32] and can be utilized in one- or multiple-session structures to engage students in this important skill area.

FIGURE 12: William & Mary - Agile Project Management CubeSat Scrum Activity

PIPELINE team members participate in the CubeSat Scrum Activity developed at William and Mary at the 2019 Summer Meeting of the American Association of Physics Teachers.

Career and Communication Skills: The GWU Capstone*

The J-TUPP panel found that one of the weakest areas in the preparation of physics students for the working world was communication skills. George Washington University (GWU) took this challenge head-on and created a new capstone experience for their students that not only required delving deeply into a research area but also included components on career development and communication [33]. Guest speakers in the class included the campus industry career coach and the director of the National Society of Physics Students. In addition to a number of in-class presentations, students were required to write article abstracts as well as draft a piece that would be suitable for *Physics Today*. These activities utilized outcomes from the Writing Transfer Project [34], which studied the difficulties students have transferring knowledge from one writing discipline to another, such as writing for a scientific audience versus a popular/public audience [35].

FIGURE 13: GWU - Communication Capstone Course*

Students participate in a capstone course developed at George Washington University. This course is designed to help students learn to conduct research in physics in an ethical manner, explore and prepare for various careers in physics, and disseminate research findings to different audiences.

*Can easily be adapted to online environments.

Selling I&E to Your Department and Administration

Why should a physics department incorporate I&E in their students' experience? Why should administrators support these efforts? First and foremost, innovation and entrepreneurship will make physics more attractive to incoming students, especially nontraditional students. As we discussed in Section 2, if physics is to attract more diverse students, it must demonstrate itself to be a discipline that has positive effects on the world—something that physics is well placed to do but does not explicitly promote. As the high school graduating classes become more diverse and as competition for students across institutions and between disciplines becomes tougher, PIE can help sustain and grow physics. Graduating larger numbers of ever more successful students will reflect back on the department and institution—in terms of both reputation as well as donations and the potential for future partnerships and alumni support.

Successfully Integrating PIE Into Physics Programs: Recommendations for Chairs and Deans

The previous section introduced a few of the myriad ways that PIE can be incorporated into the student experience. Convincing your department to do so may be a challenge. Here are ways you might approach it. Department chairs or deans can apply many of these tactics.

- Create a welcoming environment for PIE implementation, emphasizing how no physics is lost in the process, the potential for increased physics enrollment, and improved student outcomes.
- Start small! Begin in some classes with like-minded faculty, and take advantage of student enthusiasm—they are your greatest supporters.
- Hold workshops/retreats/professional development activities to introduce PIE to your faculty and to provide the background and training to allow them to incorporate it into their courses.
- Send faculty to attend meetings of organizations/societies that promote innovation and entrepreneurship education such as VentureWell [36].
- Bring, whether in person or by video, physics graduates employed in industry (such as your department alumni) to meet and speak with faculty and showcase the career needs for graduates. Work with the alumni relations office on campus to connect graduates to your department efforts.
- Reach out to chairs/deans/faculty across other departments/colleges on your campus to leverage their expertise and abilities for your students. Invite faculty from other departments into your classes as guest speakers or for team teaching. Many are already looking for ways to connect.
- Reach out to regional industries to create partnerships. Doing so can lead to site visits, industry speakers, student internships, research projects, and a better understanding of the application of physics in these domains.

- Educate the admissions office about the opportunities that physics offers to students that lead to successful and lucrative careers.
- Support faculty who are sourcing money from nontraditional funders, including industrial partners. This may require reviewing and adapting campus intellectual property policies.

4

Professional Societies, Funders, and Industry Should Support PIE—But How?

Professional societies—such as the APS, AAPT, SPS, etc.—have strategic goals that implicitly align with the outcomes of incorporating I&E into physics **(SEE FIGURE 14 ON PAGE 29)**. Professional societies, generally, want to:

- Support career development/success of their communities
- See their discipline thrive
- Broaden the spectrum of stakeholders
- Diversify and stabilize funding for their programs
- Make the world better

PIE education contributes mightily to these outcomes. Fundamentally, it makes physics more relevant to students and to addressing world problems, opens up opportunities for greater community engagement (including industry), invites financial partnerships that can support operations and research, and has the potential to recruit new and diverse audiences into the discipline.

What can societies explicitly do to help make I&E a fundamental component of physics education?

- **Publicize/promote PIE to their respective memberships**—offer dedicated, invited sessions and plenaries at meetings (along with effective advertisement), offer themed meetings based on PIE (either in connection with existing meetings or as a standalone meeting), publish dedicated journal issues (e.g., *The Physics Teacher, American Journal of Physics*, etc.), and solicit content for their digital libraries, such as comPADRE and PhysPort

- **Seek opportunities to collaborate with funders**—beyond government sources (e.g., industry) and potentially across disciplinary lines—on projects aimed at increasing PIE adoption

- **Influence policy (e.g., economic, educational, accreditation)**—for example, promote PIE to the National Science Foundation and other funders as a necessary element for the success of the discipline, lobby accrediting agencies to recognize PIE efforts as supporting student outcomes, recommend revisions to promotion and tenure standards for physics faculty to make I&E an accepted and core part of physics education and research, promote industrial funding and partnerships as qualifying as scholarly research to academic leaders
- **Promote the discipline in the context of PIE** to the general public and the secondary education community

Economic development organizations and funders need to do their part as well. Each county in the US has an EDC—a group dedicated to economic improvement in their respective regions. EDCs can help create bridges between academic institutions and regional industries and can even recruit companies to their regions to take advantage of academic capabilities. They can also help bring funding to these kinds of activities through agencies such as the Department of Commerce's Economic Development Administration (EDA) [36]. Commercialization of physics-developed technologies can also be supported by these groups, as they serve as catalysts for innovation, entrepreneurship, and business development. Physics departments need to reach out to the EDCs—and EDCs need to reach out to physics departments, as the synergies between the two can be leveraged for success for both. Chambers of Commerce and other local/regional economic development and promotional organizations such as Small Business Development Centers are also urged to take part in these important educational activities, and physics departments should reach out to them, as well.

Funding agencies need to recognize that implementing curricular and student experiential change on campuses takes more than just developing new content or pedagogical approaches—it takes sustained financial support. Creating funding vehicles that pay for implementation, and not just development, will be a critical step for institutionalizing PIE in the experience of physics students. Similarly, agencies funding physics should support research and development projects that address real-world problems beyond those that formally advance fundamental physics. Some of the approaches may be "blue sky" but could have the potential to significantly impact key areas where improved technology is needed (e.g., transportation, energy, health, the environment). The current circumstances with COVID-19 highlight the need for scientifically trained individuals to have the tools, skills, and abilities to address real-world problems, across multiple disciplines, including economic and human factors. These types of projects can still incorporate advances in physics and can be as challenging and rewarding for researchers and students as the research projects that are traditionally pursued in physics departments.

Bringing industry into the PIE education process is another step that will be needed to successfully evolve physics education for the 21st century. Partnerships between industry and academia can serve as a pipeline for technology and program development, provide expertise on which departments can draw, create opportunities for internships or job shadowing for students, and offer research opportunities for student research experiences and theses and dissertations. These kinds of partnerships pay dividends for all concerned—providing physics expertise to companies while giving students and faculty a broad range of opportunities for research, funding, and professional experience. Over the long term, investment by industry in I&E experiences for students will result in a workforce that is better prepared, more creative, and more apt to provide growth and financial return.

Figure 14: Organizations' Strategic Plans That Are Relevant to PIE

APS: "Forging new and closer ties with industry and the private sector; providing mentorship opportunities, career information, and leadership training for early-career scientists." "Play a leadership role in innovative and impactful science education, outreach, and diversity programs."

AAPT: "Providing and supporting quality professional development for physics teachers at all levels...Enrich the field by supporting the diversity of physics students and educators at all levels."

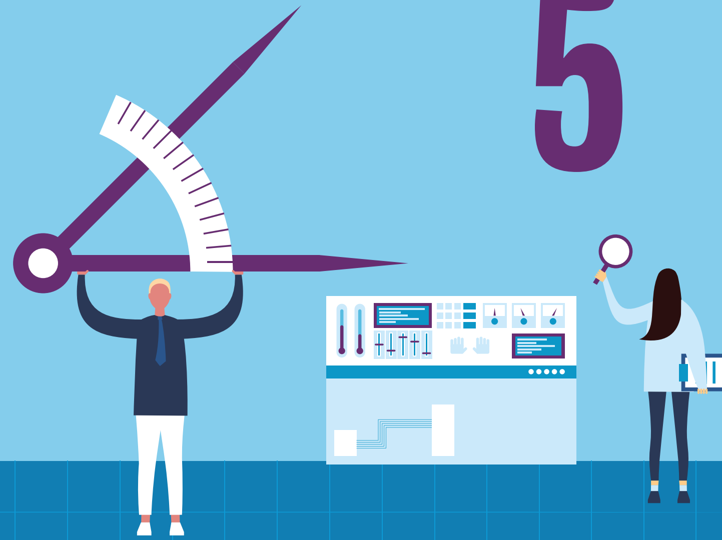
SPS: "SPS...exists to help students transform themselves into contributing members of the professional community...Other skills needed to flourish professionally include effective communication and personal interactions, leadership experience, [and] establishing a personal network of contacts."

AIP: "AIP and its Member Societies convey a unifying message for stakeholders in government, academia, the nonprofit and private sectors, the student and teacher communities, and the general public."

SIGMA PI SIGMA: "Sigma Pi Sigma exists to honor outstanding scholarship in physics, to encourage interest in physics among students at all levels, to promote an attitude of service, and to provide a fellowship of persons who have excelled in physics."

5

Resources and Opportunities



While I&E is “new” to the physics community, these kinds of educational elements have been simmering and growing in academia for over 20 years. Many of the challenges that physics faces in implementing I&E have been addressed in other disciplines in the past, and various curricular approaches have been developed that can be leveraged in physics. The community is therefore urged to take advantage of the existing communities of practitioners and the resources that have already been developed.

First and foremost are organizations that support education development in the I&E environment. These include VentureWell, which has been the leader in I&E in science and technology for over 25 years. The organization holds a conference (OPEN) each March where practitioners from many disciplines gather to share ideas and disseminate approaches that successfully engage and prepare students. A very welcoming community, eager to grow innovation and entrepreneurship education, VentureWell member institutions support organizations and disciplines that are working to include I&E in the student experience. VentureWell also offers grants to faculty for developing I&E courses and programs, grants to student teams for developing innovative products and services, and prizes at their OPEN conference for student ventures **(SEE FIGURE 15 ON PAGE 31)** [37].

The United States Association for Small Business and Entrepreneurship (USASBE) has broad interest in promoting I&E and holds a conference each year where practitioners share approaches for both education and commercialization and business development [38]. There is actually considerable overlap in skill base for physicists and engineers (as many physicists end up in positions that are also filled by engineers), which makes the American Society for Engineering Education (ASEE) another important resource for those trying to bring I&E into physics. Their annual meeting, like those of the above organizations, provides opportunities to gain insights from others who are working to enhance I&E education [39].

One of the resources that PIPELINE created is a repository of approaches for teaching physics with I&E incorporated in the student experience, some of which are outlined in the case studies of PIE implementation in Section 3. As discussed earlier, these approaches have been tested and evaluated and found to be successful in teaching the core physics principles while also achieving I&E outcomes [5]. The PIPELINE newsletter and webinar series are also valuable resources (you can subscribe at http://go.aps.org/2ZU2qqb).

PIPELINE team members are available to visit your campus, work with you and your faculty, and help promote I&E and support implementation. You can request a site visit through the PIPELINE website [5].

Another source of information and support is the "Careers 2020" report published by APS and Institute of Physics [40]. With dossiers of physics graduates working in many fields, and recommendations for students and faculty, it has a wealth of information and ideas that you can apply on your campus. Another great resource is the SPS Careers Toolbox, which describes activities that can be done by local SPS student chapters that build important career skills [41].

FIGURE 15: OPENminds Reception

Student team Burnflex showcases their innovation at the OPENminds reception at the VentureWell OPEN Conference. Visitors can "invest" play capital in their favorite teams; the team that receives the most investment wins a prize.

Photo source: VentureWell 2019

Conclusion

PIE can be a major factor in the continued success of physics departments, academic institutions, physics as a discipline, and the impact of physics on the world. It can be brought to the student experience through a variety of means and approaches that each campus can select to meet the needs, abilities, and resources available. The growing community of practitioners of I&E education is ready, willing, and able to help. It is a community we hope you will join.

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