Teaching the Whole Physics Student: Integrating Communication, Context, and Career Preparation into the Physics Curriculum

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Teaching the Whole Physics Student: Integrating Communication, Context, and Career Preparation into the Physics Curriculum

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Our big picture research goals

How can we teach practices and processes in contexts that are meaningful for classes and workplaces?

What and how can we teach students in physics to help them succeed in their desired careers?
Our Research

Exploring Multiple Postsecondary Opportunities through Workforce and Education Research

Data: Qualitative semi-structured interviews, surveys with multiple choice/select and open-ended questions

Participants: Over 50 industry managers, recent hires (<2 years), HR, faculty, students interviewed, surveys ongoing

Analysis: Qualitative coding including thematic, semantic, structural and categorical approaches

Goals: Determining factors for success in careers and connecting these with education opportunities
Why study physics? Understand the universe

NASA Astronomy Picture of the Day http://apod.nasa.gov/, N159 in the Large Magellanic Cloud
Why study physics? Solve societal problems

1. Sunlight passes through the atmosphere and warms the earth.

2. Infrared radiation (IR) is given off by the earth.

3. ...most escapes to outer space, allowing the earth to cool.

4. ...but some infrared radiation is trapped by gases in the air (including CO₂), keeping the earth warm enough to sustain life.

5. ENHANCED GREENHOUSE EFFECT
   Increasing levels of CO₂ increase the amount of heat retained, causing the atmosphere and Earth’s surface to heat up.

www.dpi.nsw.gov.au

NASA Astronomy Picture of the Day http://apod.nasa.gov/, N159 in the Large Magellanic Cloud
Why study physics? Develop technology

http://www.aimphotonics.com/
Why study physics? Get job and money

REPORT TO THE PRESIDENT
ENGAGE TO EXCEL: PRODUCING ONE MILLION ADDITIONAL COLLEGE GRADUATES WITH DEGREES IN SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS

Executive Office of the President
President’s Council of Advisors
on Science and Technology

FEBRUARY 2012

https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final_2-25-12.pdf
Where the STEM Jobs Are (and Where They Aren’t)

By STEVE LOHR  NOV. 1, 2017

Life Sciences*  183k
   12k

Engineering  169k
   51k

Physical Sciences  43k
   9k

Mathematical Sciences  33k
   7k

Computer Science  107k
   108k

So Many Degrees, So Little Demand

The number of graduates with technical majors (shown: bachelor, master and Ph.D. degrees awarded in 2015-16) tends to outpace job openings (shown: 2014-24 projections, annualized). Computer science is the exception.

* Does not include health care occupations.

Bureau of Labor Statistics, National Center for Education Statistics

Why do students go to college?

Percentage of freshmen considering these objectives “essential” or very important

<table>
<thead>
<tr>
<th>Year</th>
<th>Being very well-off financially</th>
<th>Developing a meaningful life philosophy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1971</td>
<td>37%</td>
<td>73%</td>
</tr>
<tr>
<td>1981</td>
<td>64%</td>
<td>53%</td>
</tr>
<tr>
<td>2013</td>
<td>82%</td>
<td>45%</td>
</tr>
</tbody>
</table>

Freshman Survey, Higher Education Research Institute at UCLA
Hey Prof.
Sorry that I haven't emailed you sooner but it has been a hectic weekend for me. I just wanted to let you know that the interview went really well on Thursday. So well that today they offered me the job working on their Cylindrical Lenses as an Engineer!!!!!! Thank you so much for everything you have done. If it weren't for you, I would never have taken that first tour of the company.
Audience input!

What paths are your current physics majors thinking of pursuing after graduation?

Type your (short) answers into the chat window.
Where do physics majors go after graduating?

Status of Physics Bachelors One Year After Degree, Classes of 2013 & 2014 Combined

Graduate Study

<table>
<thead>
<tr>
<th>Physics &amp; Astronomy</th>
<th>Other Fields</th>
<th>Employed</th>
<th>Unemployed</th>
</tr>
</thead>
<tbody>
<tr>
<td>32%</td>
<td>22%</td>
<td>41%</td>
<td>5%</td>
</tr>
</tbody>
</table>

Figure based on 4,886 individuals.

http://www.aip.org/statistics
Audience input!

Across undergraduate physics, what do you think will help students most in their future paths?

Type your (short) answers into the chat window.
Transferable processes and practices

Broadly applicable as trends and technologies rapidly evolve.

Cognitive (scientific and technical)  Problem solving

Interpersonal  Communication

Intrapersonal  Perseverance

Relevance of specialized technical knowledge

• Tidy alignment between degree and job duties is not the norm
• A physics degree signals you can learn complex technical subjects and solve complex problems
• Specialized technical knowledge is essential for contributing at work.
• But a lot can be learned on the job
Inter- and intrapersonal learning before job

Employer perceptions of workplace training:

- Most trainable
- Cognitive (scientific and technical)
- Interpersonal
- Intrapersonal

- Least trainable
Context affects how tasks are done

Adapted from Finkelstein (2004) Learning physics in context: a study of student learning about electricity and magnetism
Problem 10.18 Suppose a point charge $q$ is constrained to move along the $x$ axis. Show that the fields at points on the axis to the right of the charge are given by

$$E = \frac{q}{4\pi \epsilon_0} \frac{1}{z^2} \left( \frac{c+v}{c-v} \right) \hat{x}, \quad B = 0.$$ 

What are the fields on the axis to the left of the charge?

9.35 A wagon wheel is constructed as shown in Fig. E9.35. The radius of the wheel is 0.300 m, and the rim has mass 1.40 kg. Each of the eight spokes that lie along a diameter and are 0.300 m long has mass 0.280 kg. What is the moment of inertia of the wheel about an axis through its center and perpendicular to the plane of the wheel? (Use the formulas given in Table 9.2.)
Problem solving in a classroom context

Idioculture
small group culture

Situation

Problem solving

Graded on answer
Student
Student-student
Mechanics, E&M (single content area)
Desks
Study room
Some answers in back of book or online
Textbook
Pencil/paper
Calculator
Learning Grade
Work with other physics majors (all night if necessary)
Individual learning prioritized

Each problem has one right answer

Adapted from Finkelstein (2004) Learning physics in context: a study of student learning about electricity and magnetism
Problem solving in a workplace context

Idioculture
small group culture

Situation
Technicians and engineers
Blueprints
Software
Ask questions
Take initiative

Problem solving

Client-driven
Manufacturing floor
Design and fabrication

Company first mindset
Consider costs/time

Safety
Documentation

Adapted from Finkelstein (2004) Learning physics in context: a study of student learning about electricity and magnetism
Teaching practices and processes in meaningful workplace contexts

INTEGRATING COMMUNICATION
Communication in a classroom context

Richard Feynman lecturing in 1962 on optics and Pierre de Fermat’s principle of least time.
Communication in a public context
Communication in a workplace context

- Interdisciplinary collaborator
- Manager, advisor
- Clients, customers
- Co-workers with different expertise
- Other experts in similar field
- General public
Communicating across occupations

With co-workers with different expertise

“One of the big things is ... to communicate with those who do not necessarily understand all of the physics behind what they're doing.”

Makers

Modelers and designer

\[
Z = \frac{C_x X^2 + C_y Y^2}{1 + \sqrt{1 - C_x^2 X^2 - C_y^2 Y^2}} \quad C_x = \frac{1}{R_x} \quad C_y = \frac{1}{R_y}
\]
Communicating with clients

“Presentation is huge. You can know all the right things, but if you don’t know how to read that information in a clear, easy to read and understandable way, you’re just going to confuse customers...”

https://www.linkedin.com/pulse/role-sales-engineer-technical-mikhail-frolov
“Definitely not being afraid to speak up.

A lot of people have the problem where if they speak up and they ask a question that identifies a gap in their knowledge, they feel that brings them down a rung in other people's eyes.

But really, that's something that we value here is the ability just to ask a question.”
Asking questions at work

- **Asks a lot of questions**
  - Curious, eager learner, leads new directions, solves new problems, builds on team and supporting resources

- **Dependent**
  - Uses questions to avoid taking initiative
  - Passive, waits for others to give instruction

- **Independent**
  - Loner, tries to solve everything on their own
  - Wasting time/money/effort

- **Does not ask questions**
Communication with documentation

When asked “What communication skills need improvement?”

“Documentation...and not only with formal documentation but even in any type of written communication keeping people apprised of what they’re doing. They (new hires) don’t share information.”

-Supervisor of engineers

“Most [grad students] described training in lab notebook use as either ineffective or outright missing from their undergraduate lab course experience.”

Stanley & Lewandowski Phys Rev PER (2016)

Recommendations for the use of notebooks in upper-division physics lab courses
American Journal of Physics 86, 45 (2018); https://doi.org/10.1119/1.5001933
Need for communication instruction in physics

Physics graduates may be missing important training and experience:

- Ability to function on multidisciplinary teams
- Ability to recognize value of diverse relationships (customers, supervisors, etc.)
- Communication skills (oral and written) – esp. how to tailor message to audience

ABET survey of applied and engineering physics graduates, Kettering University
Acoustic Reflectometer

Introduction

An acoustic reflectometer is a useful tool for studying many fundamental properties in applied sciences, in particular, the electron acoustic waves. This experiment explores the properties of the medium, and it also explores the physics of acoustic waves.

The primary focus of this experiment is to understand how acoustic waves are generated within a tube, and how these waves propagate within the medium. It is essential to understand the physics of the medium, and it is important to recognize the significance of the medium's properties. The medium's properties are essential in determining the characteristics of the wave, and it is important to understand the physics of the medium to gain a deeper understanding of the wave's behavior.

The medium's properties are closely related to the medium's density and elasticity. The density of the medium affects the speed of sound in the medium, and the elasticity of the medium affects how much energy is stored in the medium.

The medium's properties can be measured using a variety of techniques, including interferometry and spectrometry. These techniques can be used to determine the medium's density and elasticity, and they can be used to determine the characteristics of the wave.

The medium's properties are also affected by the medium's temperature and pressure. The temperature of the medium affects the medium's density and elasticity, and it is important to understand the physics of the medium to determine the characteristics of the wave.

The medium's properties are also affected by the medium's orientation. The orientation of the medium affects the medium's density and elasticity, and it is important to understand the physics of the medium to determine the characteristics of the wave.

The medium's properties are also affected by the medium's geometry. The geometry of the medium affects the medium's density and elasticity, and it is important to understand the physics of the medium to determine the characteristics of the wave.

The medium's properties are also affected by the medium's time-dependent behavior. The time-dependent behavior of the medium affects the medium's density and elasticity, and it is important to understand the physics of the medium to determine the characteristics of the wave.

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Integrating communication into physics

General resources
Oral Communication in the Disciplines: A Resource for Teacher Development and Training

Specific resources
Teaching Tip: Improving Students' Email Communication through an Integrated Writing Assignment
- Adapt to client’s needs and wants
- Present information clearly and concisely
- Account for varying degrees of understanding
- Mock e-mail assignment
Cooperative Group Problem Solving
University of Minnesota, PER group

Problems are complex enough that one student is not enough

Rotate through specific roles:
• Manager
• Recorder/checker
• Skeptic
• Energizer/summarizer

Includes evaluation tools for group function
Teaching teamwork for projects

Help faculty manage students’ team experiences
- Assigning students to teams
- Peer Evaluation
- Rater Practice
- Teamwork training
- Meeting support

http://info.catme.org/

https://journals.aom.org/doi/abs/10.5465/amle.2010.0177
Teamwork training

Diagnostic tools for evaluating and improving team performance. (Kedrowicz, NCSU)

**Parker Team-Player Survey:**
Are you a Contributor, Collaborator, Communicator, or Challenger?

**Team Profile:**
Based on composition of team member styles, ID team’s strengths, limitations, and strategies

**Team Meeting Reaction Form:**
Accomplishments, Cohesiveness, Clarity of Goals, Cooperation, Productivity, Suggestions

**Group Member Peer Evaluation:**
Listening, flexible, supportive, open to feedback, easy to talk to, punctual
Teaching communication in physics

- Communication is diverse in professional settings
- Students need meaningful communication activities that contribute to a larger goal
- Communication is integrated with the science
- Resources are available to support instructors
- Communication is teachable and should be taught with physics
  - Teaching Communication: Theory, Research and Methods
Communication occurs in meaningful contexts

Epistemologies in Practice: Berland, Schwarz, Krist, Kenyon, Lo, & Reiser (2016)
PHYSICS IN DESIGN CONTEXTS
A design quote from physics students...

“[Design] I guess that's more of an engineering thing.”

~Physics Undergraduate Students

What do you think?
Physics graduates may be missing important training and experience in the ability to design a system, component or process to meet a specific need.

ABET survey of applied and engineering physics graduates, Kettering University
Design is ubiquitous in research and industry

- Apparatus
- Experiments
- Software

Designing with computational models

Lab learning goals emphasize design

AAPT Lab Recommendations
“Having a real good **hands-on type attitude** and mind-set. The type of people that are most successful here are the ones that don't want to just sit in the cubicle all day. They **want to design** something, and get it **built** and touch it and **fix it** because it may not work the first time, and understand the whole design process.”

~Manager
“The idea is we get the [digital] design, we get the test bench all figured out, how things are going to work, and then depending on the system I might have to assemble the lens, or it might come to me assembled by a manufacturing engineer...I then install it on the test bench, take measurements, find out what aspects of the performance it is meeting, what aspects it’s falling short on, and then try to diagnose how to fix that.”

~Recent Hire
Reflections on Design as a Context

1. **Goal** is different: Make a thing that does this
   1. It is highly relevant process for career prep
   2. No one solution is best, student directed, multiple solutions, multiple paths
   3. Iterative extended projects complement undergraduate research

2. **Tools** are different: Physical and digital prototyping

3. **People** collaborate based on a need for creativity and complementary expertise
Teaching a design process

Iterate

Understand

Test

Define

Explore

Implement

Ideate

Prototype

Refine _ Choose

Borrow ideas from Engineering Educators

From VEX Robotics EDR Curriculum
https://curriculum.vexrobotics.com/curriculum/intro-to-engineering/what-is-the-engineering-design-process.html
Teaching in Design/Making Contexts

Provide Opportunities to Design and Make

• Have students select tools and set up labs as part of doing experiments
• Value troubleshooting more than “correct” results
• Apply theoretical physics toward models and digital designs using software
• Encourage students to participate in design projects and Maker Spaces
• Develop maker skills through pop-up courses (APS PIPELINE Webinar)

Other resources from APS PIPELINE Project

• Building technical competencies for projects
• Template for student innovation projects
• Bibliography on creativity, product development, innovation, entrepreneurship, business
Teaching practices and processes in meaningful workplace contexts

MATHEMATICS IN ACTION
Mathematics in a classroom/theory context
<table>
<thead>
<tr>
<th>Conceptual modeling</th>
<th>Realistic analytical-numerical modeling</th>
<th>Design-oriented modeling</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Goal:</strong> mechanistic explanation</td>
<td><strong>Goal:</strong> accurate predictions</td>
<td><strong>Goal:</strong> design based on specific requirements</td>
</tr>
<tr>
<td>Iteratively build models, identify assumptions</td>
<td>Extend simple models with real-world complexity</td>
<td>Determine parameters and tolerances</td>
</tr>
<tr>
<td>Explore trends</td>
<td>Employ computational tools, programming</td>
<td>Limited by constraints</td>
</tr>
<tr>
<td><strong>Outcome:</strong> diagram and equations that model system</td>
<td><strong>Outcome:</strong> specific numerical solution</td>
<td><strong>Outcome:</strong> Schematics, blueprints,</td>
</tr>
</tbody>
</table>
Math use depends on context (data and measurement)

- Measurements needed are determined by client parameters
- Accuracy and precision needed depends on the purpose
- Integrates multiple science and math practices
- Linked with tool selection and use
- Often involves geometry in optics

“How the light is coming out and *what’s actually happening during the measurements is huge. The more people understand why, the more effective they are.*”

~Recent Hire
Math use depends on context (software tools)

Using computational tools is essential

• Excel, a spreadsheet tool
• General purpose modeling and data analysis – MATLAB, Mathematica, Python. R
• Specialized modeling tools – COMSOL multiphysics simulation, CodeV optics

Integrate Programming across the Curriculum

• Teach at least one broadly applicable language in depth (Python, MATLAB)
• Allow students to search online and ask others for help
"My biggest piece of advice is learn the numerical and computational methods. Do it because, otherwise, you can't contribute. Yes, you're great at physics and, yes, you have a good intuitive understanding, but without being able to actually model things in real life, it's going to be impossible to...it's not impossible to contribute, but you're going to be much more effective. I think that's something that has been my advice, and I've told many physics students."

~Recent Hire
Resources for integrating computation

Partnership for Integration of Computation into Undergraduate Physics  [https://www.compadre.org/PICUP/](https://www.compadre.org/PICUP/)

AAPT Recommendations for Computational Physics in the Undergraduate Physics Curriculum

Teaching practices and processes in meaningful workplace contexts

EXPANDING PHYSICS CONTEXTS
What contexts should we apply to physics learning?

- Idioculture
  - small group culture

- Situation
  - student
  - tools
  - concept
  - goals
  - local environment

- Task
  - rules
  - behavior norms
  - expectations
What can be done in classrooms?

Think about the broader roles, goals, tools, and environments

- **Goals:** Design challenges, interpreting data, taking measurements
- **Tools:** computation and programming (e.g., Python, Excel) in both theory and lab courses
- **Environments:** laboratory, maker spaces
- **Roles:** designer, fabricator, client, etc.

Develop and highlight intersecting processes (technical and scientific, interpersonal, and intrapersonal) into courses
What can be done beyond the classroom?

Send students in to new contexts:

- Encourage co-ops and internships
- Field trips
- Maker spaces
- Popup courses
- Interdisciplinary projects

Explore APS PIPELINE network for recommendations to integrate innovation and entrepreneurship in physics
**Other Resources**

**SPS Physics Careers Toolbox**
Practical activities for identifying career options, writing resumes, etc.

**AIP Statistics** has lots of data on employment about physics degree holders
**Who’s Hiring Physics Bachelors**

**APS Careers** a gateway for information about physics jobs and careers. Find physics job listings, career advice, upcoming workshops and meetings, and career and job related resources.

APS PIPELINE Network

• Six member institutions: Loyola University Maryland, Rochester Institute of Technology, Wright State, UC Denver, and George Washington University.

• Advised by experts from established physics entrepreneurship programs (e.g. Carthage College, Case Western, Kettering University)

• Goals are:
  • to **deliver tested PIE curriculum** to a wider cohort of practitioners.
  • to **assess of effects of PIE implementation** on student and faculty attitudes towards innovation and entrepreneurship, and **examine barriers** to PIE implementation
  • to **build a community** of expert practitioners who can mentor other institutions.

• Activities are varied in scope and resources needed; institutions varied in culture and resources available.

www.aps.org/programs/education/innovation/index.cfm
Thank you

Get in touch!

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www.rit.edu/power