Teaching the Whole Physics Student:

Integrating Communication, Context, and Career Preparation into the Physics Curriculum

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- Dial in or use your computer's microphone and speakers.
- Submit questions via the Questions panel on the right.
- This session is being recorded.
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Teaching the Whole Physics Student:

Integrating Communication, Context, and Career Preparation into the Physics Curriculum

April 25, 2018

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NSF

R·I·T

POWER
Photonics and Optics Workforce Education Research

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

POWER
Photonics and Optics Workforce Education Research

AIM photonics

EMPOWER
Exploring Multiple Postsecondary Opportunities through Workforce and Education Research

APS physics | PIPELINE

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

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

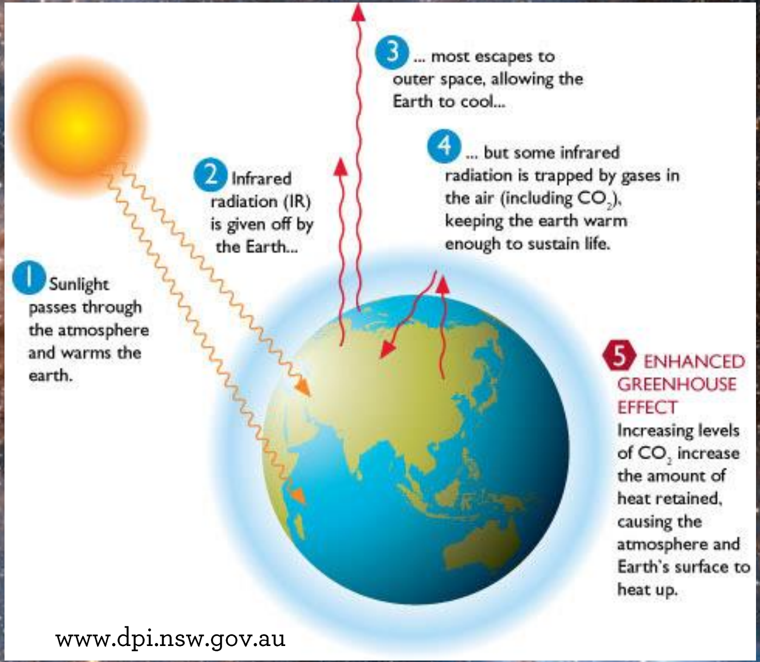
Analysis: Qualitative coding including thematic, semantic, structural and categorical approaches

Goals: Determining factors for success in careers and connecting these with education opportunities

Why study physics? Understand the universe

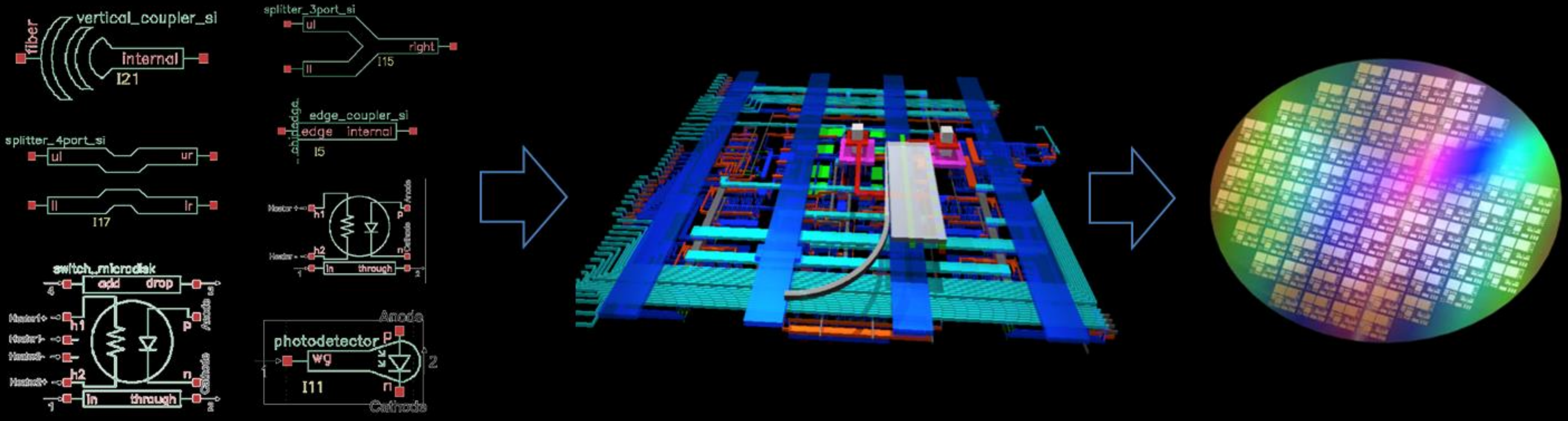
NASA Astronomy Picture of the Day http://apod.nasa.gov/, N159 in the Large Magellanic Cloud

Why study physics? Solve societal problems



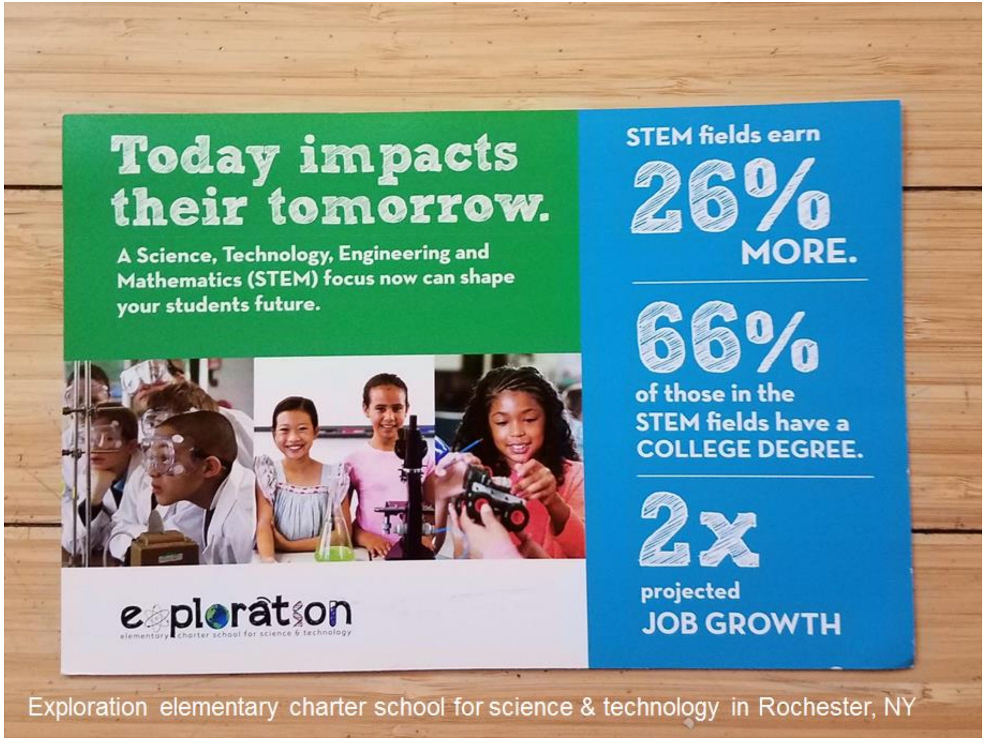
NASA Astronomy Picture of the Day http://apod.nasa.gov/, N159 in the Large Magellanic Cloud

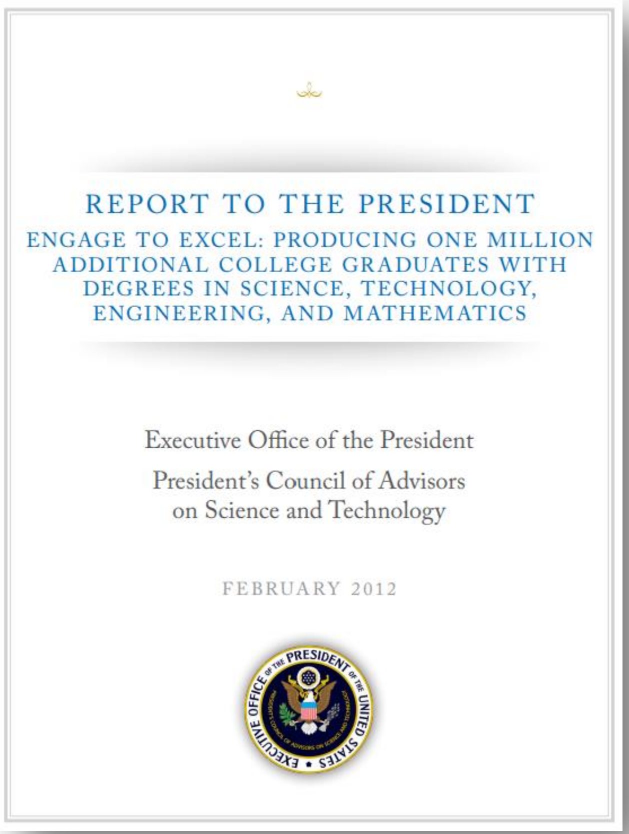
Why study physics? Develop technology



http://www.aimphotonics.com/

Why study physics? Get job and money





https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final_2-25-12.pdf

Wait a minute! Where are the STEM jobs?

Where the STEM Jobs Are (and Where They Aren't)

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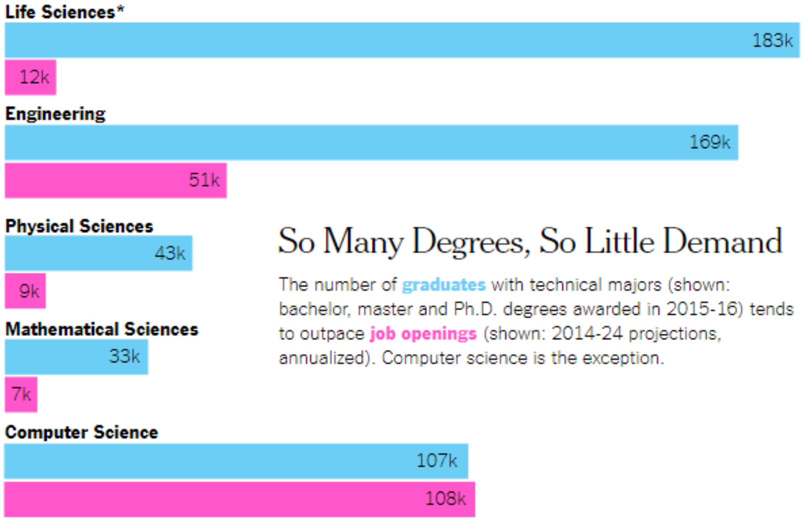
By STEVE LOHR NOV. 1, 2017



*Does not include health care occupations.

Bureau of Labor Statistics, National Center for Education Statistics

https://www.nytimes.com/2017/11/01/education/edlife/stem-jobs-industry-careers.html

Why do students go to college?

Percentage of freshmen considering these objectives "essential" or very important

Year	Being very well-off financially	Developing a meaningful life philosophy
1971	37%	73%
1981	64%	53%
2013	82%	45%

Freshman Survey, Higher Education Research Institute at UCLA

Finding meaning at work

Subject	Interview

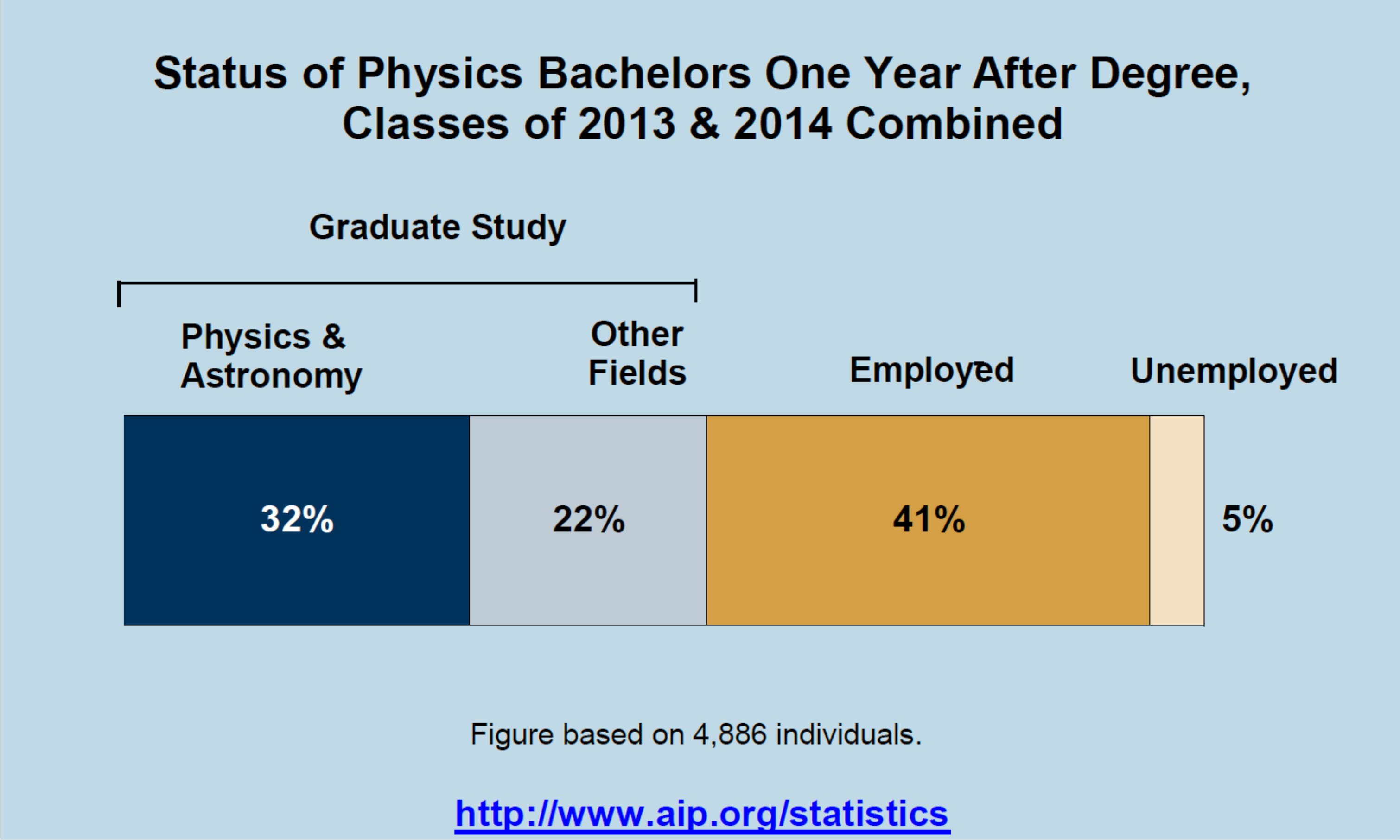
Hey Prof.
Sorry that I haven't emailed you sooner but it has been a hectic weekend for me. I just wanted to let you know that the interview went really well on Thursday. So well that today they offered me the job working on their Cylindrical Lenses as an Engineer!!!!!! Thank you so much for everything 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?



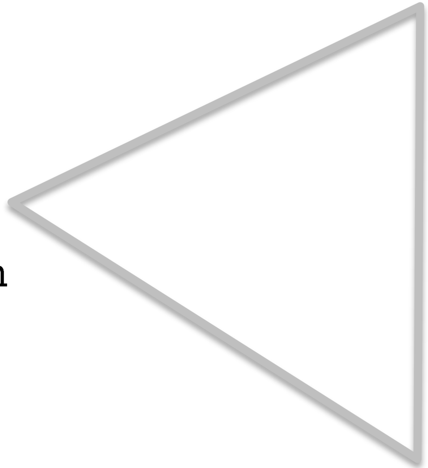
Audience input!

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.



NRC, Education for Life and Work Developing Transferable Knowledge and Skills in the 21st Century (2012)

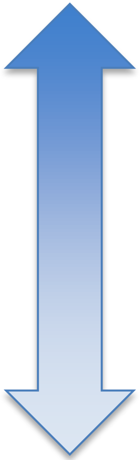
Relevance of specialized technical knowledge

- **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:

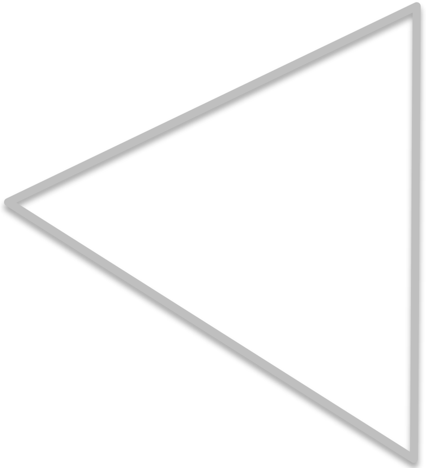
Most trainable



Least trainable

Cognitive (scientific and technical)

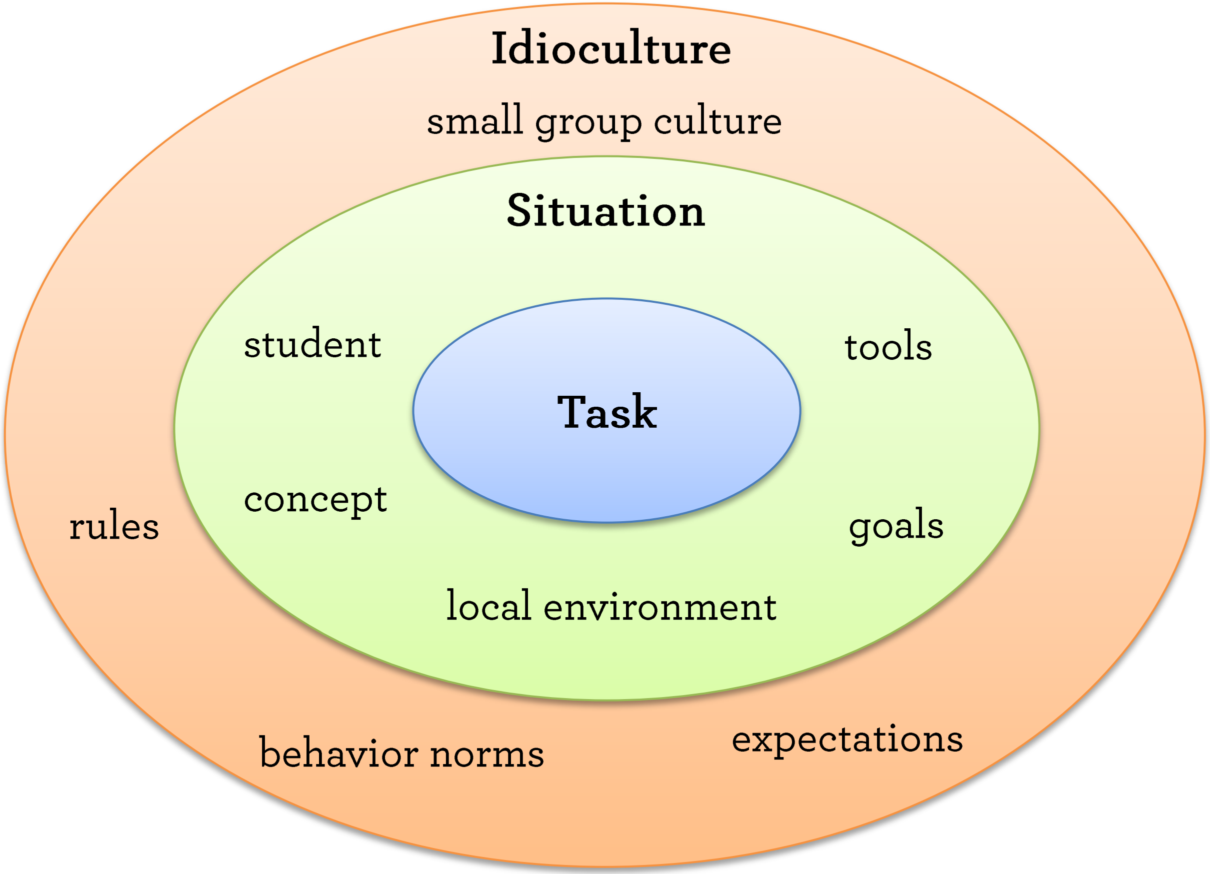
Interpersonal



Intrapersonal

CONTEXT

Context affects how tasks are done



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

Example: Problem solving

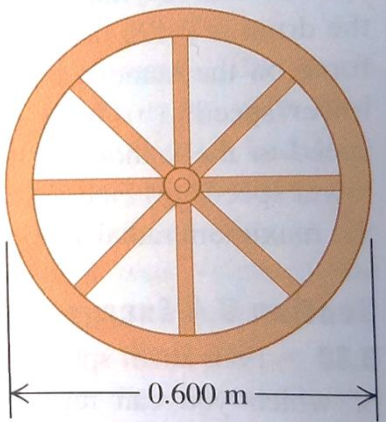
Problem 10.18 Suppose a point charge q is constrained to move along the x axis. Show that the fields at points on the axis to the *right* of the charge are given by

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

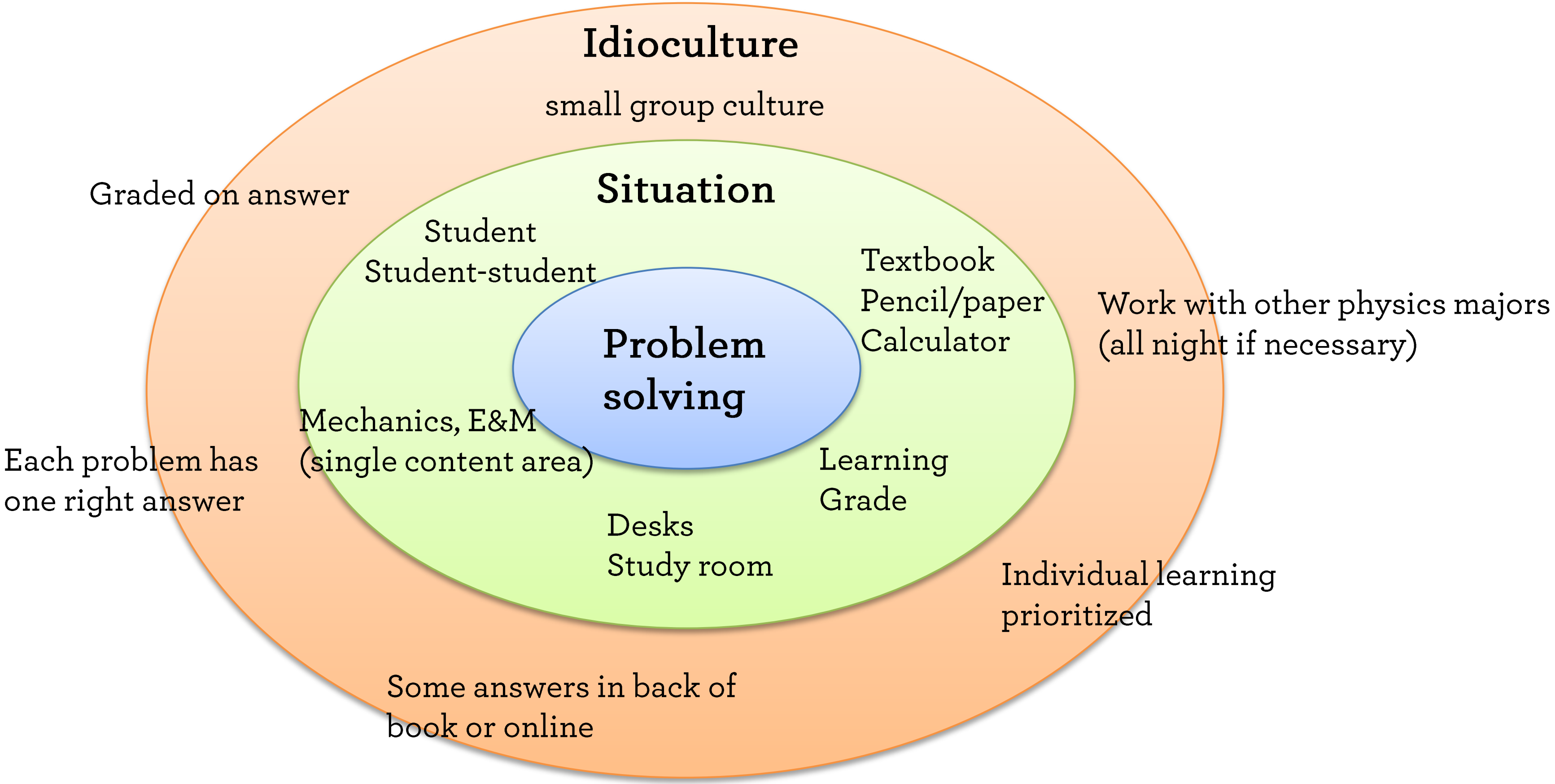
What are the fields on the axis to the *left* of the charge?

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.)

Figure **E9.35**

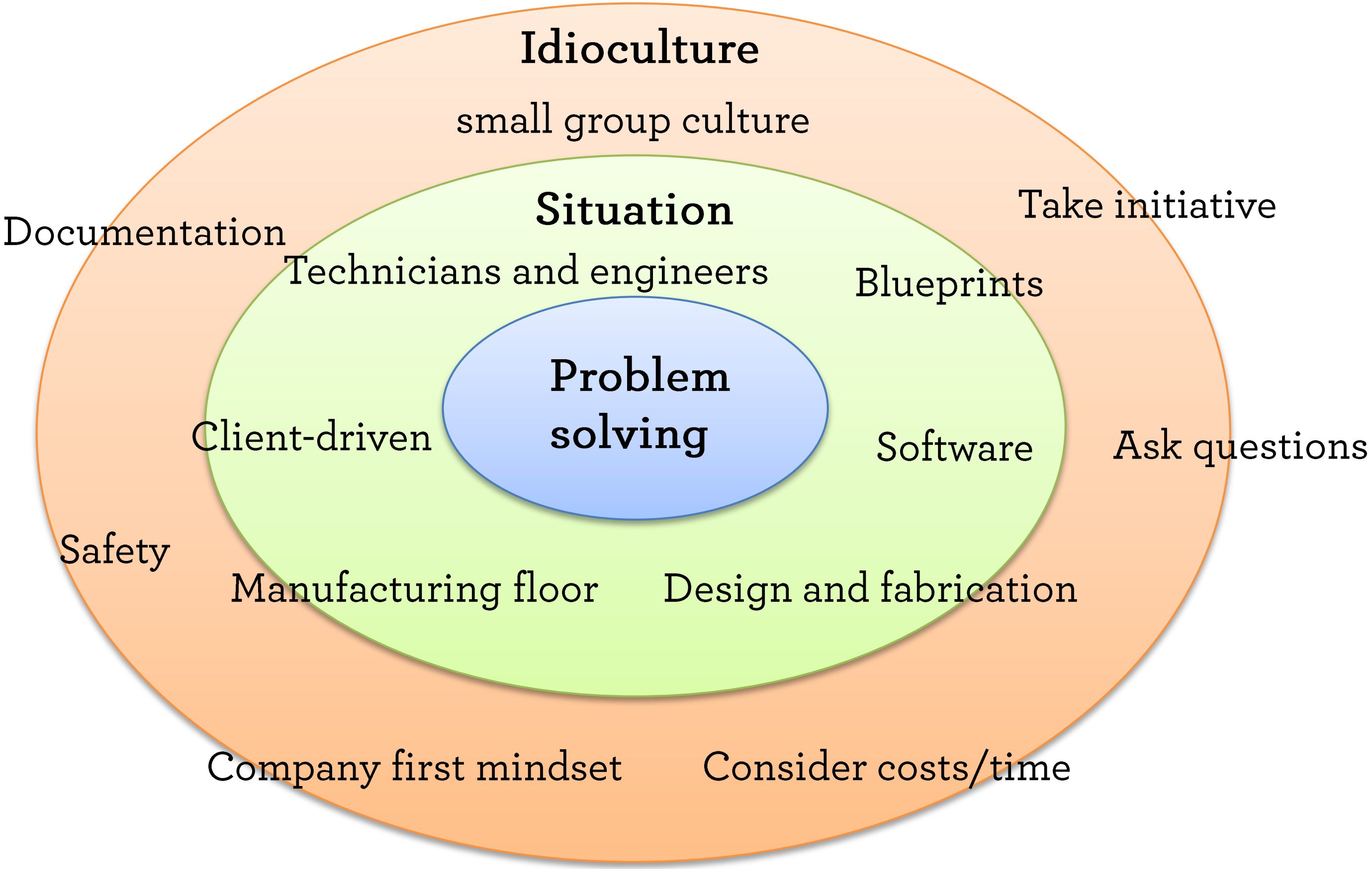


Problem solving in a classroom context



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

Problem solving in a workplace context

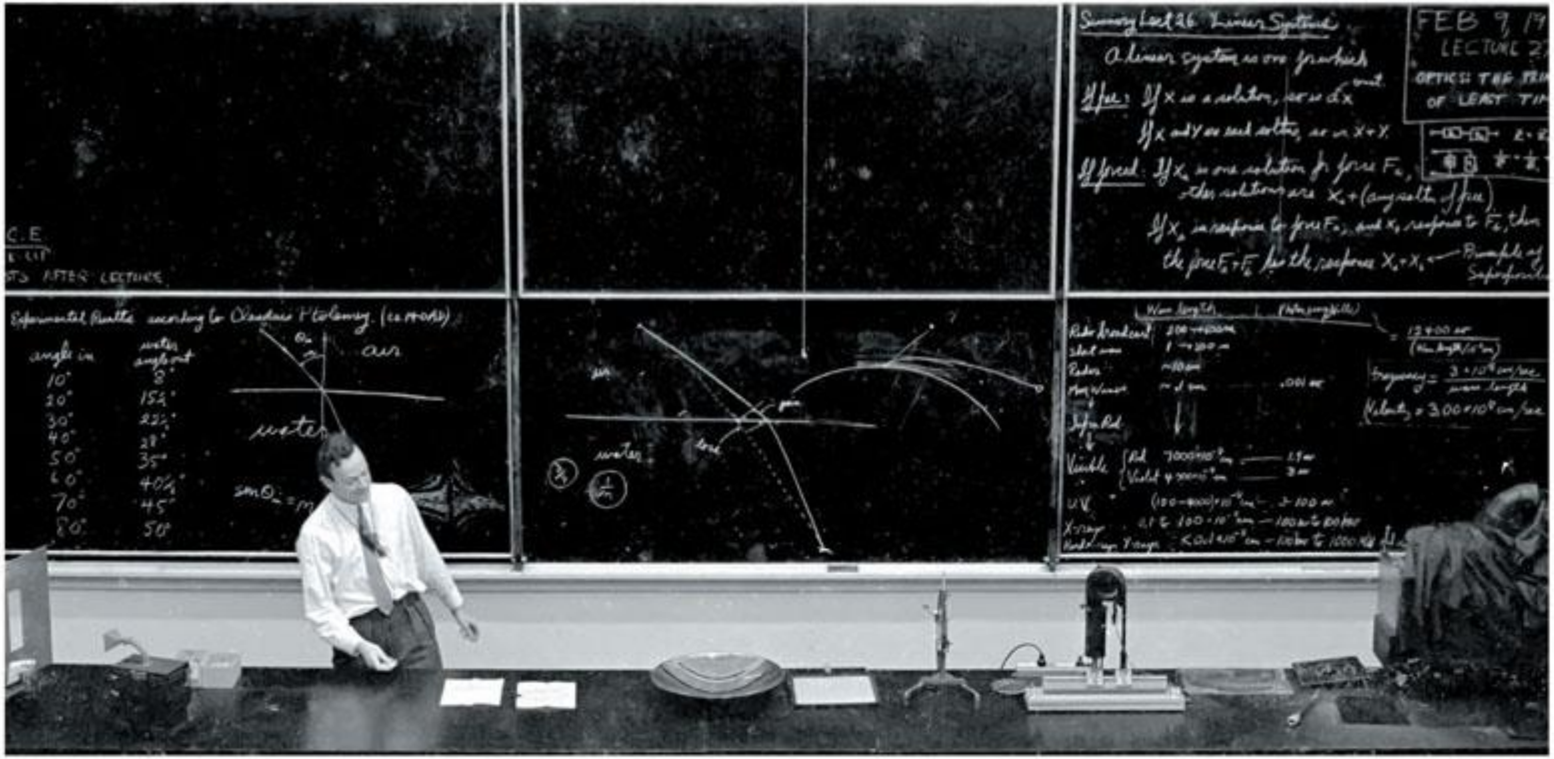


Adapted from Finkelstein (2004) [Learning physics in context: a study of student learning about electricity and magnetism]

Teaching practices and processes in meaningful workplace contexts

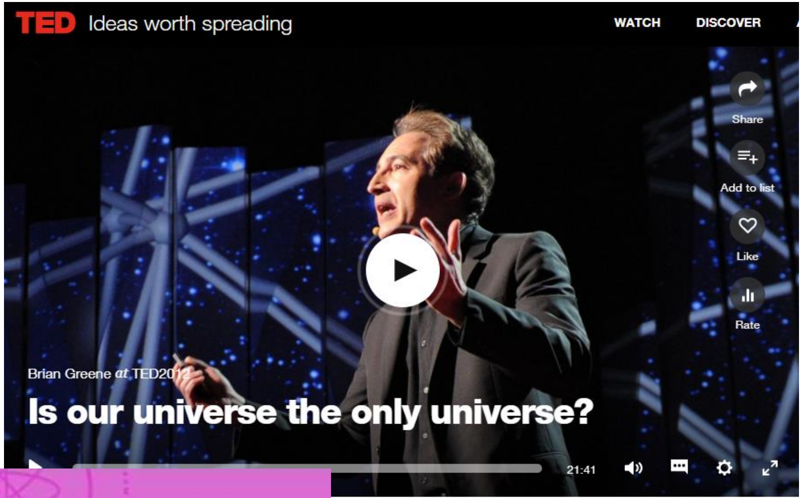
INTEGRATING COMMUNICATION

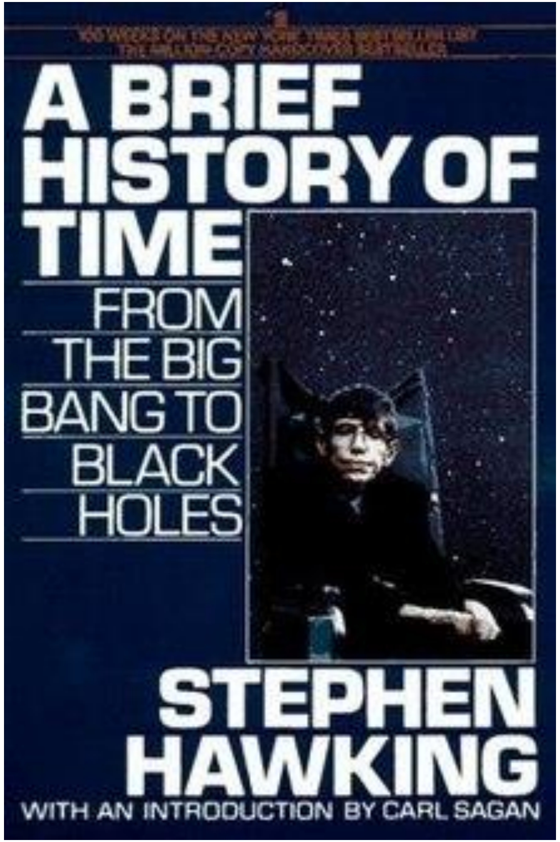
Communication in a classroom context

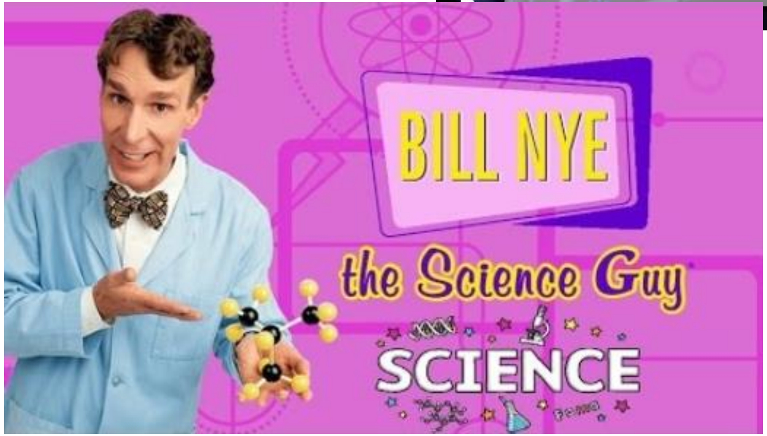


Richard Feynman lecturing in 1962 on optics and Pierre de Fermat's principle of least time.

Communication in a public context

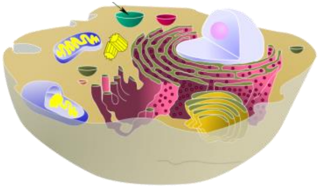






Communication in a workplace context

Interdisciplinary collaborator

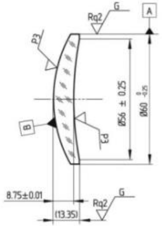


Manager, advisor

Clients, customers

You

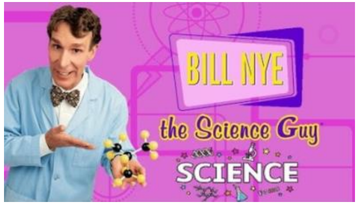
Co-workers with different expertise



Other experts in similar field

APS physics

General public

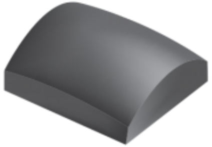


Communicating across occupations

With co-workers with different expertise

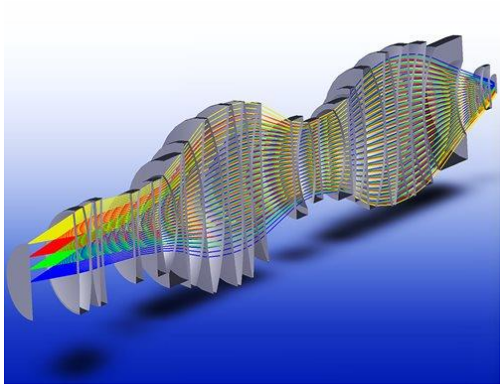
“One of the big things is … to communicate with those who do not necessarily understand all of the physics behind what they're doing.”

Makers



Toroid

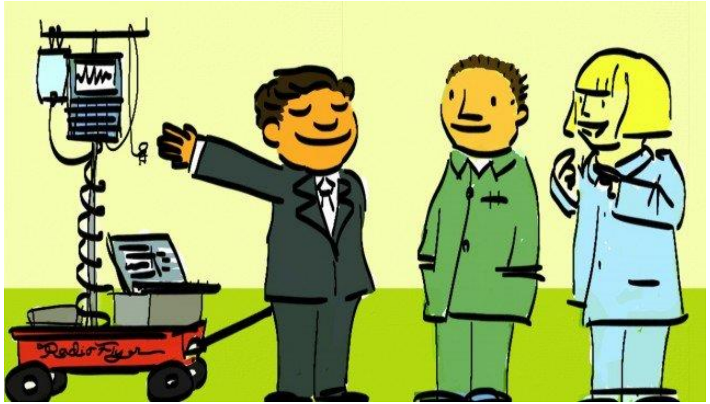
$$Z = \frac{C_xX^2 + C_yY^2}{1+\sqrt{1-C_x^2X^2-C_y^2Y^2}} \quad C_x = \frac{1}{R_x} \quad C_y = \frac{1}{R_y}$$



Modelers and designer

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

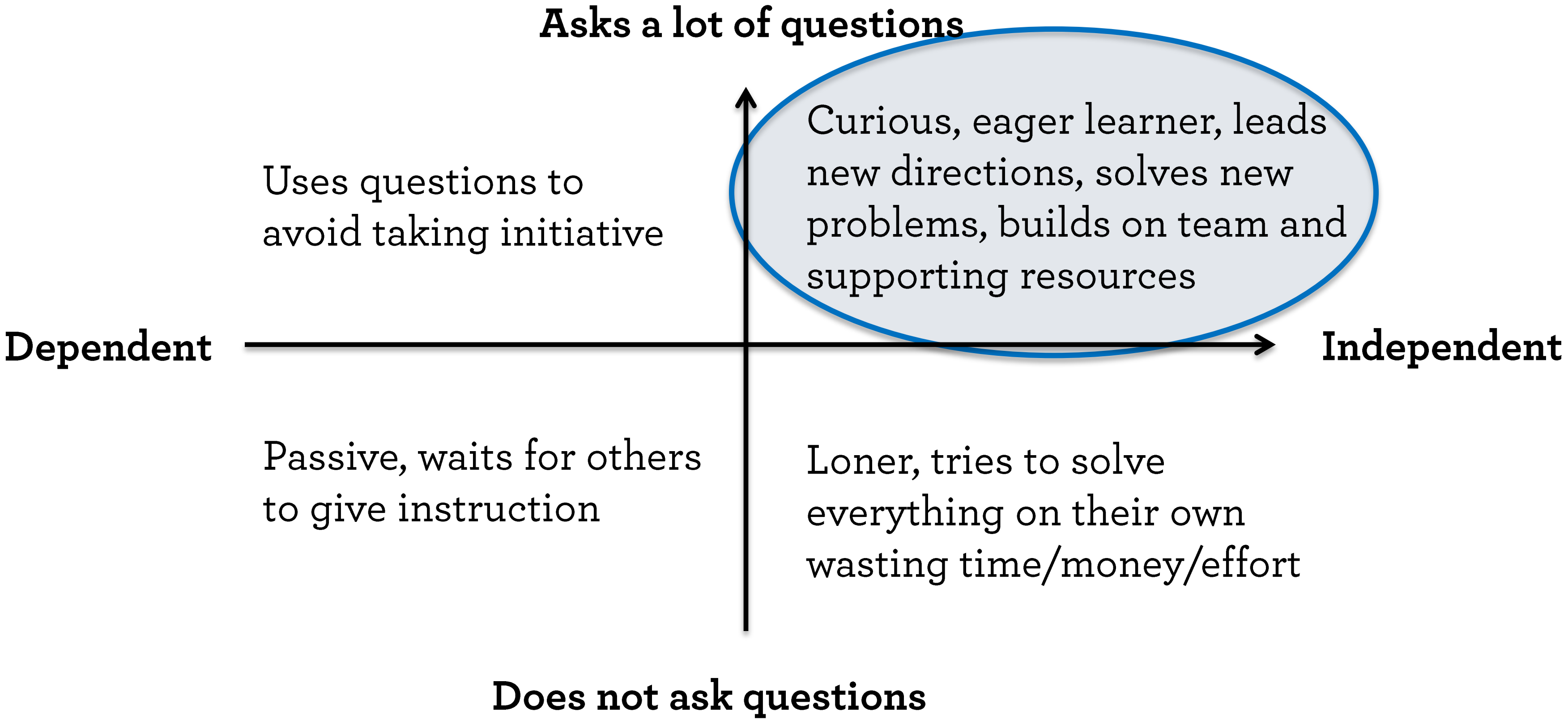
Asking questions at work...

"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



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

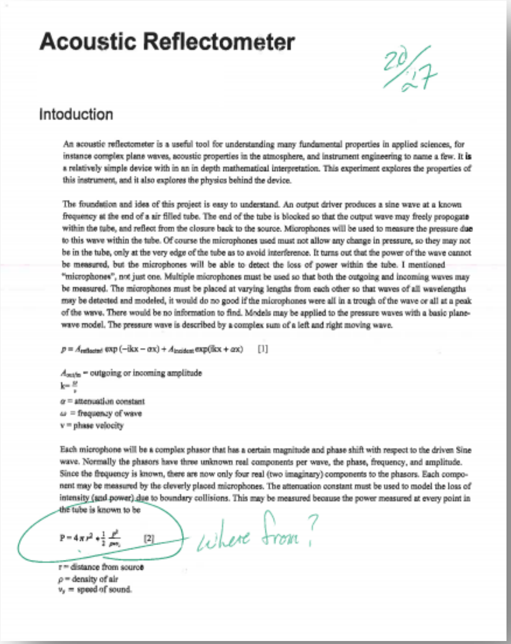
Need for communication instruction in physics

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

Beyond lab reports and presentations



Acoustic Reflectometer

20/27

Intoduction

An acoustic reflectometer is a useful tool for understanding many fundamental properties in applied sciences, for instance complex plane waves, acoustic properties in the atmosphere, and instrument engineering to name a few. It is a relatively simple device with in an in depth mathematical interpretation. This experiment explores the properties of this instrument, and it also explores the physics behind the device.

The foundation and idea of this project is easy to understand. An output driver produces a sine wave at a known frequency at the end of a air filled tube. The end of the tube is blocked so that the output wave may freely propogate within the tube, and reflect from the closure back to the source. Microphones will be used to measure the pressure due to this wave within the tube. Of course the microphones used must not allow any change in pressure, so they may not be in the tube, only at the very edge of the tube as to avoid interference. It turns out that the power of the wave cannot be measured, but the microphones will be able to detect the loss of power within the tube. I mentioned "microphones", not just one. Multiple microphones must be used so that both the outgoing and incoming waves may be measured. The microphones must be placed at varying lengths from each other so that waves of all wavelengths may be detected and modeled, it would do no good if the microphones were all in a trough of the wave or all at a peak of the wave. There would be no information to find. Models may be applied to the pressure waves with a basic plane-wave model. The pressure wave is described by a complex sum of a left and right moving wave.

$$p = A_{reflected} \exp(-ikx - \alpha x) + A_{incident} \exp(ikx + \alpha x) \quad [1]$$

$A_{out/in}$ = outgoing or incoming amplitude

$k = \frac{\omega}{v}$

α = attenuation constant

ω = frequency of wave

v = phase velocity

Each microphone will be a complex phasor that has a certain magnitude and phase shift with respect to the driven Sine wave. Normally the phasors have three unknown real components per wave, the phase, frequency, and amplitude. Since the frequency is known, there are now only four real (two imaginary) components to the phasors. Each component may be measured by the cleverly placed microphones. The attenuation constant must be used to model the loss of intensity (and power) due to boundary collisions. This may be measured because the power measured at every point in the tube is known to be

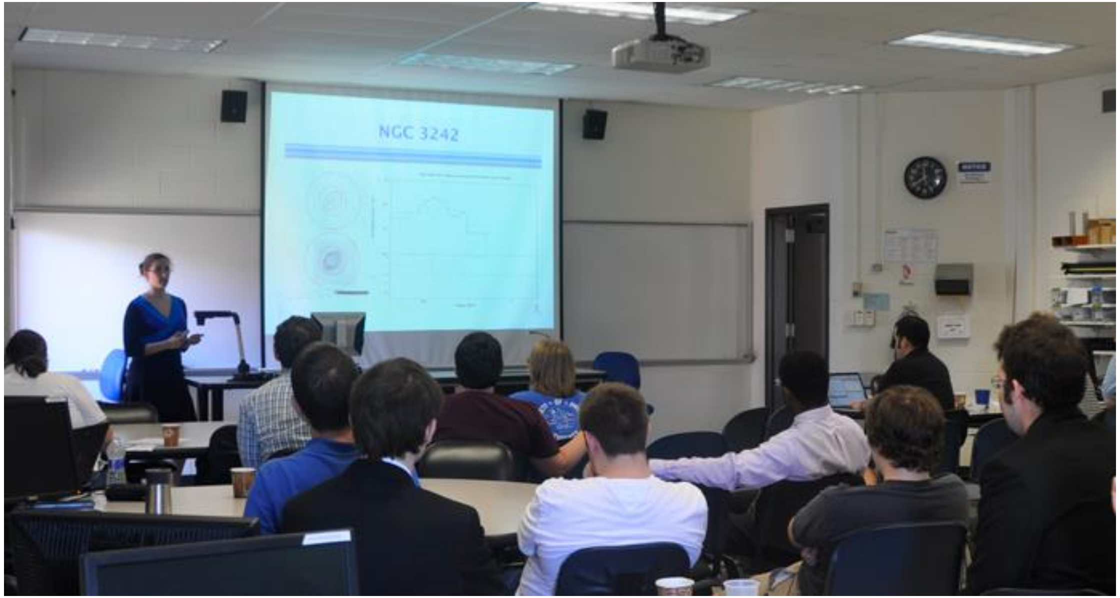
$$P = 4\pi r^2 \cdot \frac{1}{2} \frac{p^2}{\rho v_s} \quad [2]$$

where from?

r = distance from source

ρ = density of air

v_s = speed of sound.



Integrating communication into physics

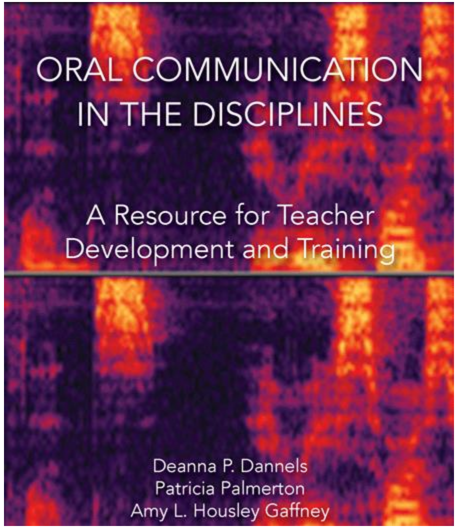
General resources

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



Teaching teamwork in intro physics

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

CATME

SMARTER Teamwork

http://info.catme.org/

Help faculty manage students' team experiences

- Assigning students to teams
- Peer Evaluation
- Rater Practice
- Teamwork training
- Meeting support

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

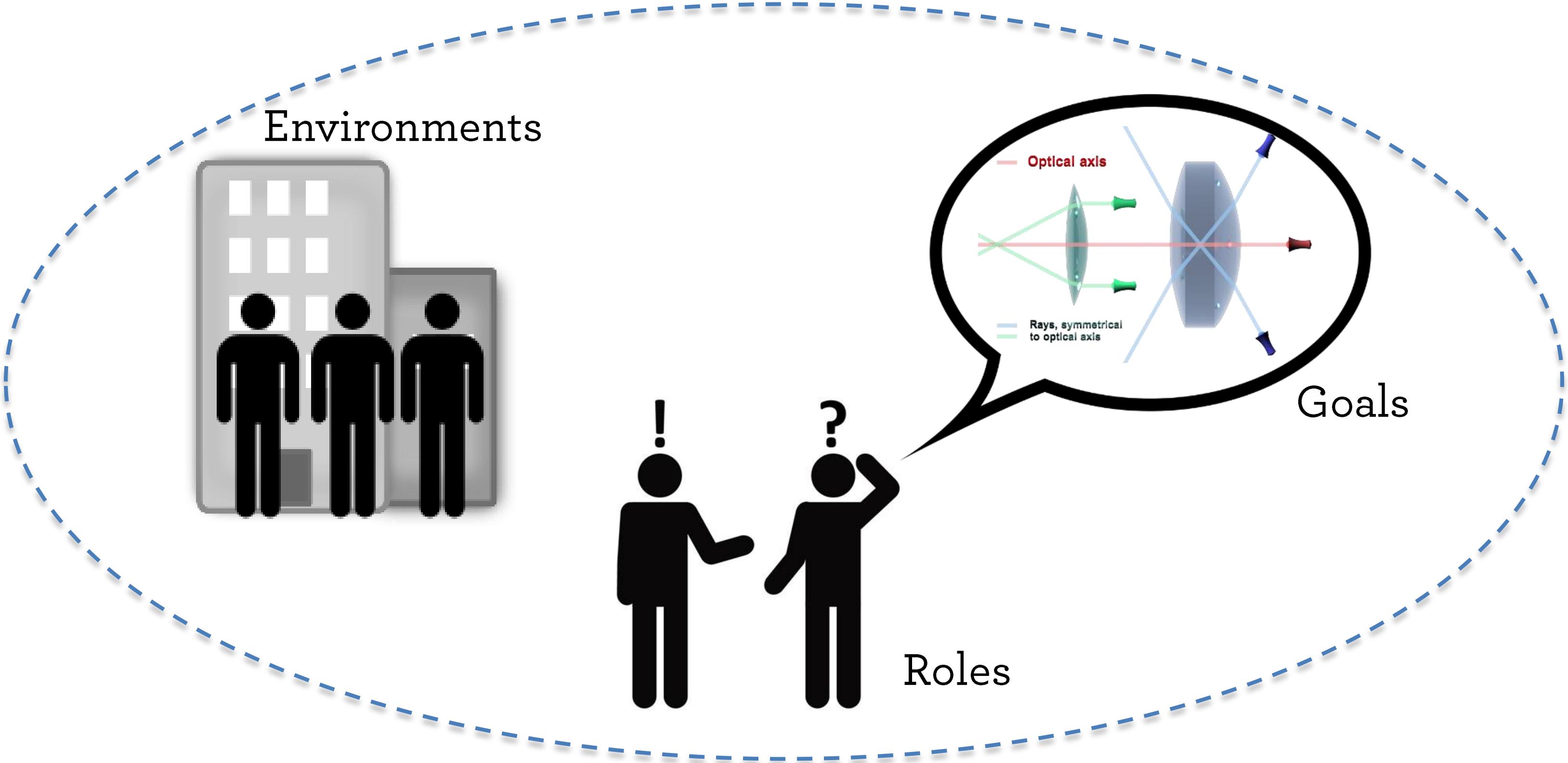
Team Meeting Reaction Form:
Accomplishments, Cohesiveness, Clarity of Goals, Cooperation, Productivity, Suggestions

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



Communication in the Disciplines: Sullivan & Kedrowicz (2012)
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?

From the employer perspective...

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

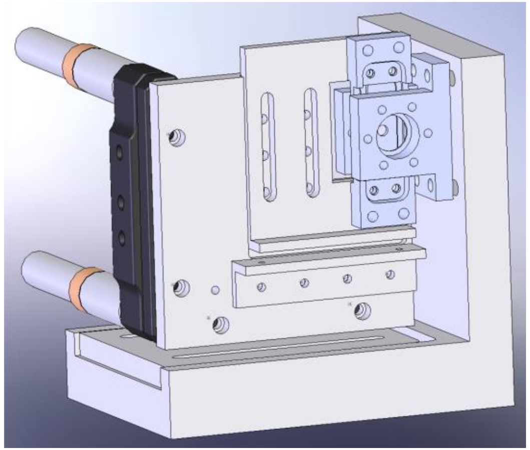
ABET survey of applied and engineering physics graduates, Kettering University

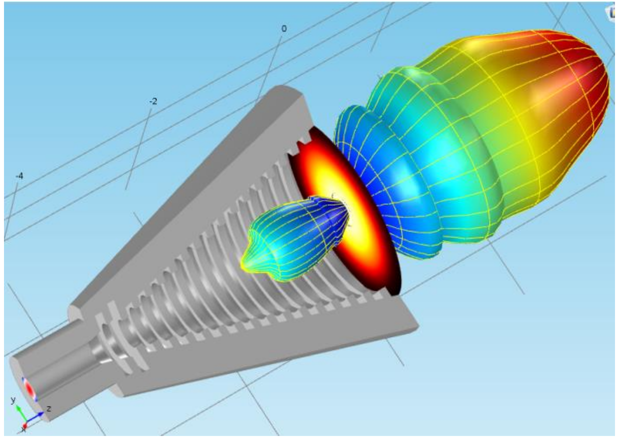
Design is ubiquitous in research and industry

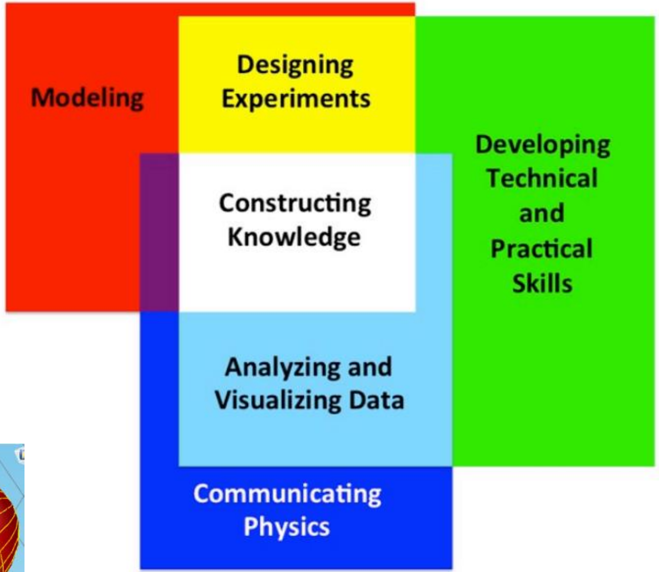
- Apparatus
- Experiments
- Software

Designing with computational models

Lab learning goals emphasize design





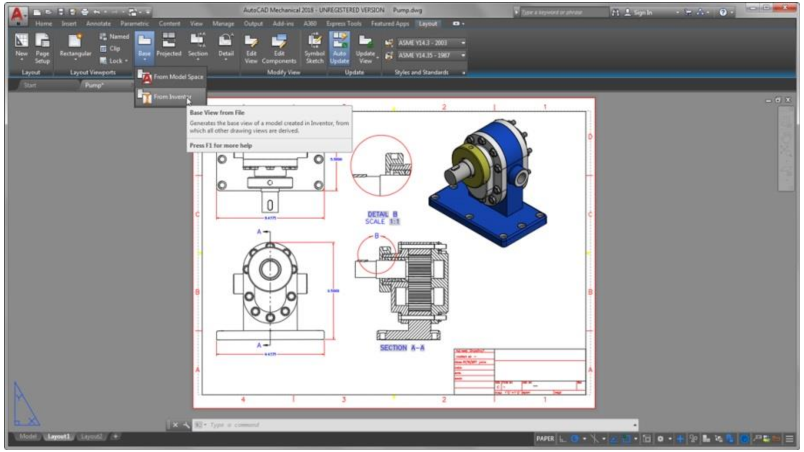


[AAPT Lab Recommendations]

Design in the workplace

*"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



Design: Prototyping

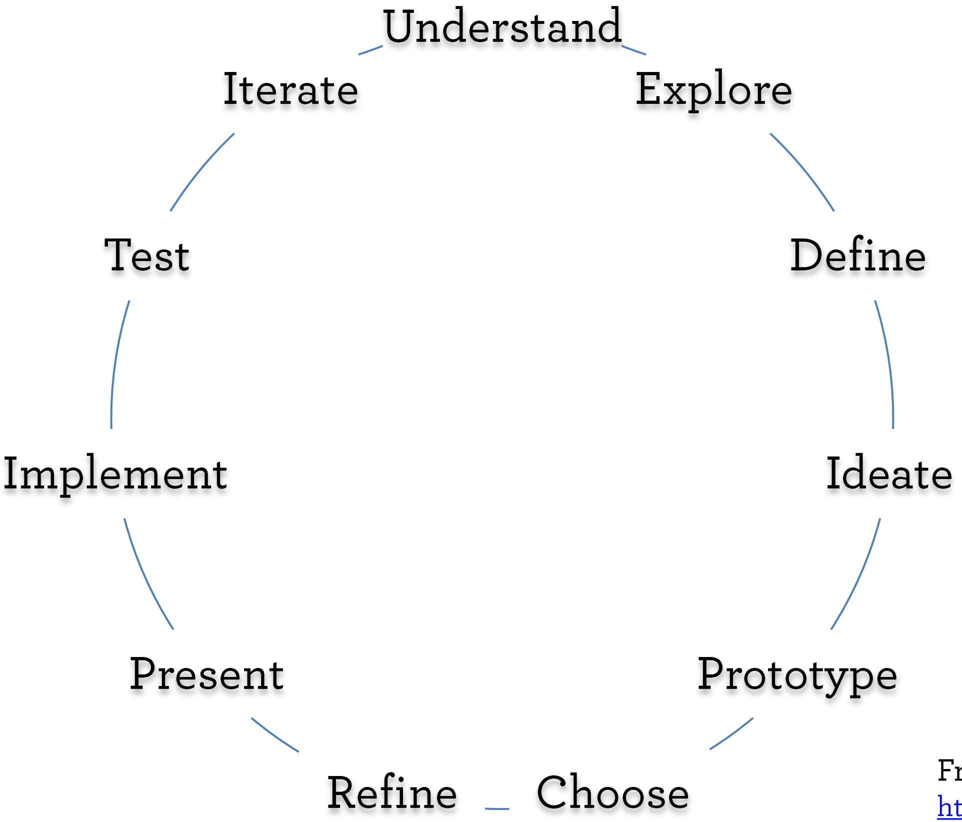
"The idea is we get the [digital] design, we get the test bench all figured out, how things are going to work, and then depending on the system I might have to assemble the lens, or it might come to me assembled by a manufacturing engineer...I then install it on the test bench, take measurements, find 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



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)

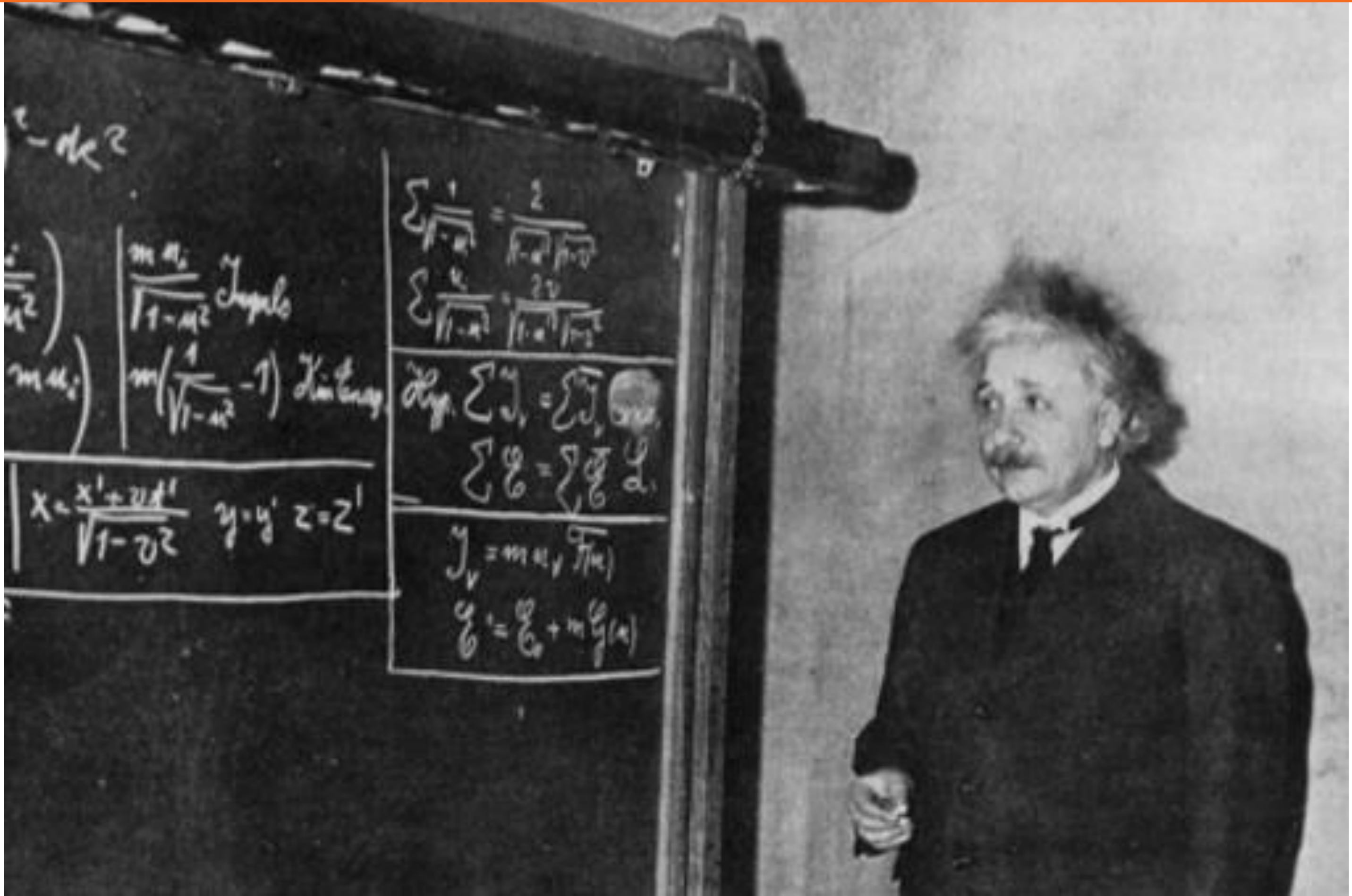
Other resources from APS PIPELINE Project

- Building technical competencies for projects
- Template for student innovation projects
- Bibliography on creativity, product development, innovation, entrepreneurship, business

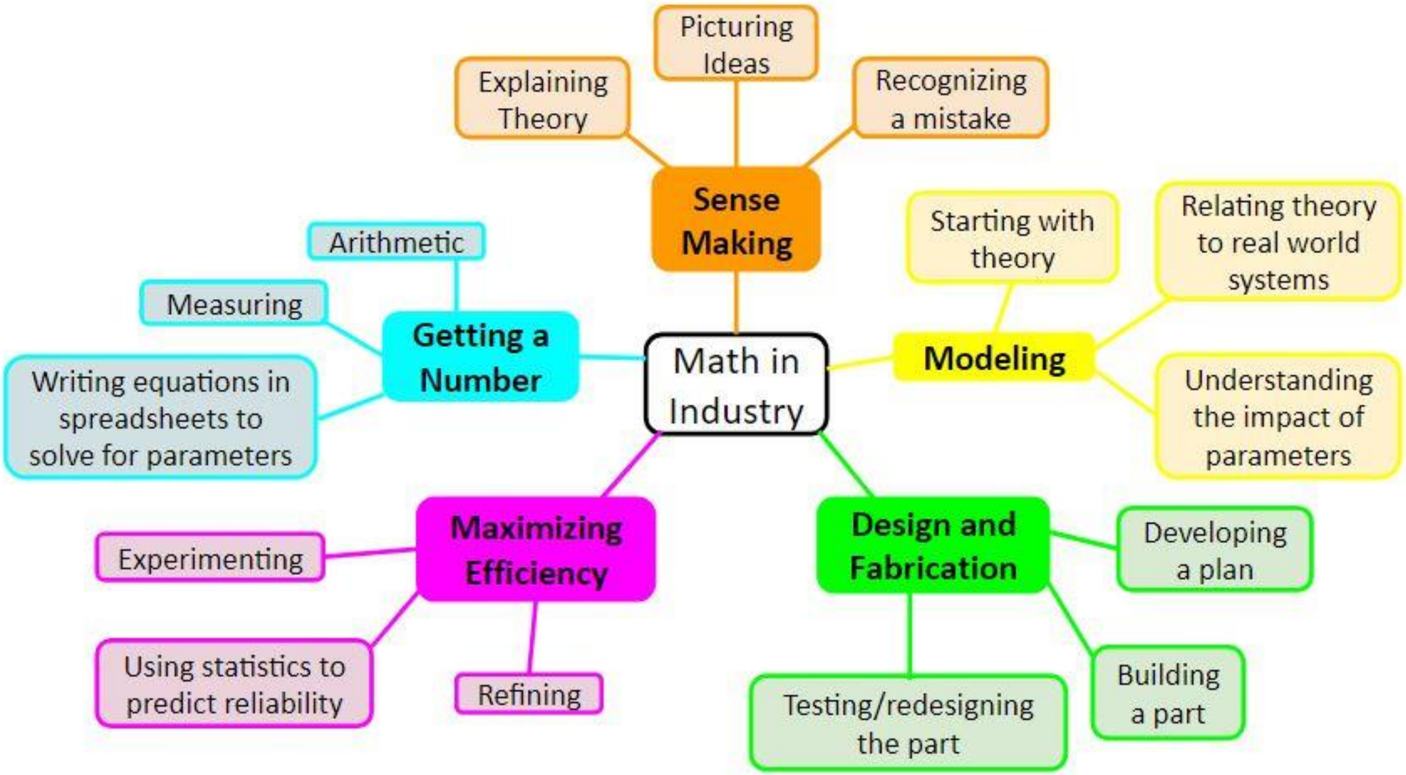
Teaching practices and processes in meaningful workplace contexts

MATHEMATICS IN ACTION

Mathematics in a classroom/theory context



Mathematics in a workplace context



Kingston Chen

Math use depends on context (modeling goal)

Conceptual modeling

Goal: mechanistic explanation

Iteratively build models, identify assumptions

Explore trends

Outcome: diagram and equations that model system

Realistic analytical-numerical modeling

Goal: accurate predictions

Extend simple models with real-world complexity

Employ computational tools, programming

Outcome: specific numerical solution

Design-oriented modeling

Goal: design based on specific requirements

Determine parameters and tolerances

Limited by constraints

Outcome: Schematics, blueprints,

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

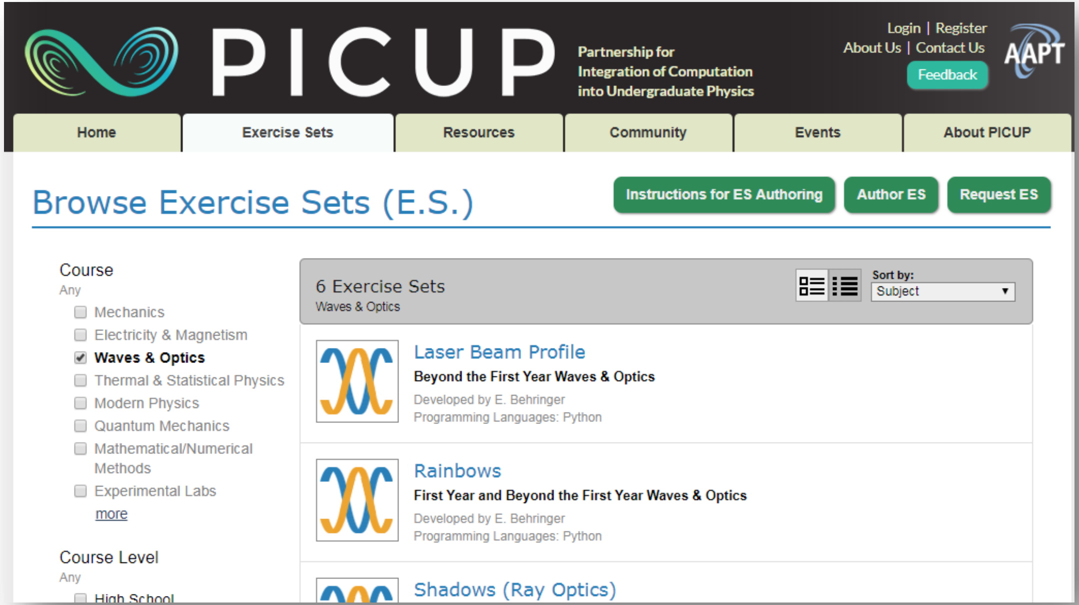
- Teach at least one broadly applicable language in depth (Python, MATLAB)
- Allow students to search online and ask others for help

The need for computation in physics

"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/

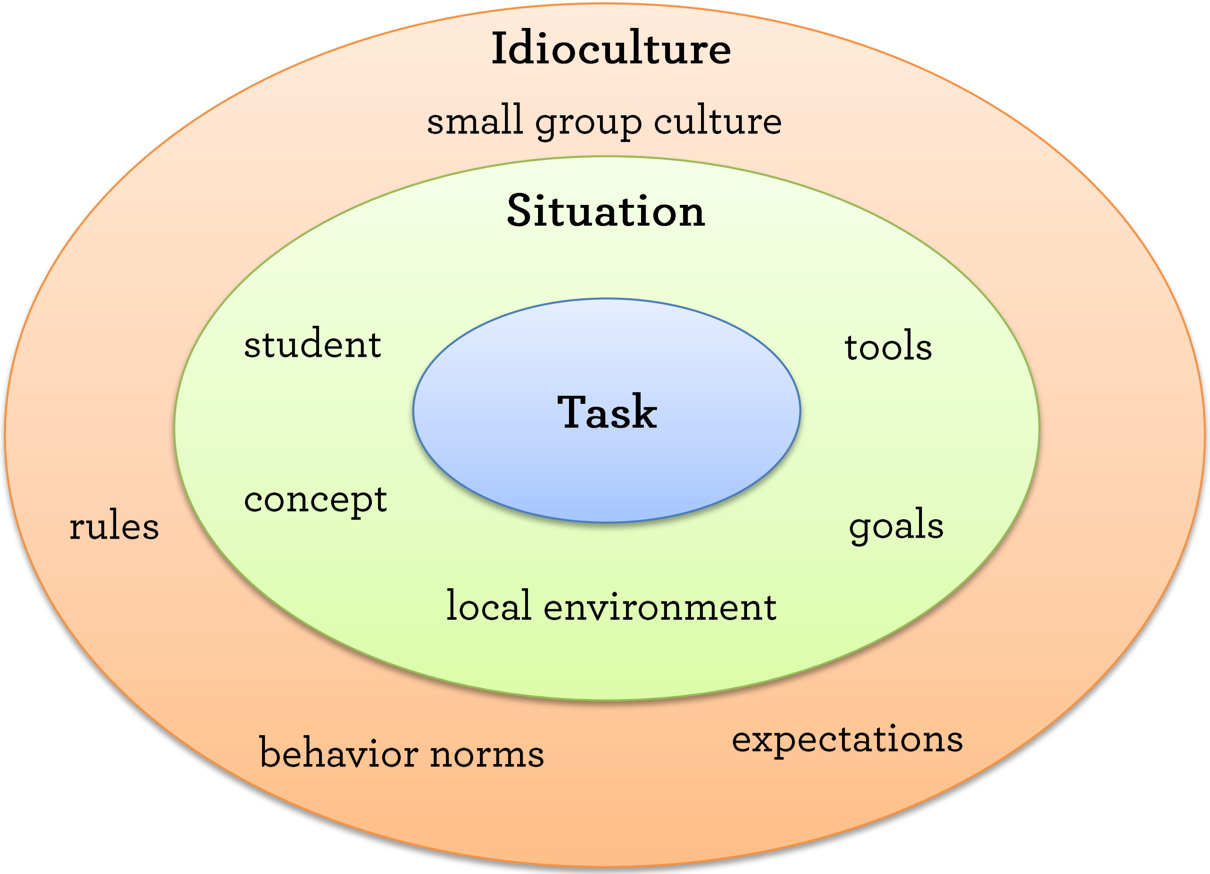
[AAPT Recommendations for Computational Physics in the Undergraduate Physics Curriculum]()

Weintrop, D. *et al.* [Defining Computational Thinking for Mathematics and Science Classrooms](). *Journal of Science Education and Technology* **25,** 127–147 (2016).

Teaching practices and processes in meaningful workplace contexts

EXPANDING PHYSICS CONTEXTS

What contexts should we apply to physics learning?



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, <u>and</u> 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.

Phys 21 Report and Supplement - A report on preparing physics students for 21st century careers. Covers preparation for students as well as suggestions for departments.

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

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Thank you

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