Assessing Computational Knowledge and Skills: The Role of the Community

PICUP Capstone Conference
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Department of Computational Mathematics, Science, and Engineering
CREATE For STEM Institute
Fictitious Case: Simon (he/him)
Fictitious Case: Simon (he/him)

I want to help my students work through their physics assignments. They struggle with different things, but from year to year, it seems like the same kinds of things show up over and over.
Physics educators have developed lots of formative assessment tools and strategies.
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The underlying physics of an electric motor is that

a) electric and magnetic fields repel each other.

b) a current-carrying wire experiences force in a magnetic field.

c) like magnetic poles repel each other.

d) ac voltage is induced by a changing magnetic field.

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The energy for a car moving on a hill is diagrammed above.
1. Did the car speed up or slow down?
2. Was it moving uphill or downhill?

Justify each of your claims with evidence and reasoning.
Physics educators have developed lots of formative assessment tools and strategies.
Fictitious Case: Mo (they/them)
I really want to see what my students can do with the physics knowledge they have. I want to challenge them.
Physics educators have developed a variety of summative assessment approaches.
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Fictitious Case: Zoey (she/her)
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I have been teaching physics for several years, but I don’t know if I’m doing it effectively. I really don’t know if things are improving each year, but it feels like my students are learning.
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Questions x-z refer to a coin that is tossed straight up into the air. After it is released it moves upward, reaches its highest point and falls back down again. Use one of the following choices (A through G) to indicate the acceleration of the coin during each of the stages of the coin’s motion described below. Take up to be the positive direction. Answer choice J if you think that none is correct.

A. The acceleration is in the negative direction and constant.
B. The acceleration is in the negative direction and increasing
C. The acceleration is in the negative direction and decreasing
D. The acceleration is zero.
E. The acceleration is in the positive direction and constant.
F. The acceleration is in the positive direction and increasing
G. The acceleration is in the positive direction and decreasing

x. The coin is moving upward after it is released.
y. The coin is at its highest point.
z. The coin is moving downward.
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What about Computation in Physics?
There's lots to consider!

- Physics
  - Application
- Computational Physics
- Computer Science
  - Hardware/Software
- Math
  - Techniques
There’s lots to consider!

Focus on:
- Concepts?
- Practices?
- Attitudes?
- Dispositions?
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- Concepts?
- Practices?
- Attitudes?
- Dispositions?

*Each talk in this session has a different focus*
Why evidence-based assessment?
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Adopting evidence-based assessments has helped drive changes to instruction including pedagogy and curriculum.
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Science Education

Challenge faculty to transform STEM learning
Focus on core ideas, crosscutting concepts, and scientific practices


Models for higher education in science, technology, engineering, and mathematics (STEM) are under pressure around the world. Although most STEM faculty and practicing scientists have learned successfully in a traditional format, they are the exception, not the norm, in their success. Education should support a diverse population of students in a world where using knowledge, not merely memorizing it, is becoming ever more important. In the United States, which by many measures is a world leader in higher education, the President’s Council of Advisors on Science and Technology (PCAST) recommended sweeping changes to the first 2 years of college, which are critical for retooling deep learning and is well aligned with other international initiatives. These strategies were developed for K-12 (primary and secondary education), but we believe the approach is valid for the first 2 years of college.

CORE IDEAS, CROSSCUTTING CONCEPTS.
Disciplinary experts have a great deal of knowledge—organized and contextualized around important concepts (5). Students should develop knowledge around these “disciplinary core ideas” rather than try to assemble understanding from many disparate ideas and activities. Core ideas should be advanced over time through carefully developed progressions of learning activities national-level initiatives and the research literature, we believe that core ideas must be negotiated locally by faculty in each discipline in order to build ownership and buy-in.

For example, core ideas that emerged from cross-disciplinary discussions at our institution, Michigan State University (MSU), include “evolution” for biology, “structure and properties” for chemistry, and “interactions cause changes in motion” for physics. Focusing on core ideas within each discipline allows reduction of the amount of material that many agree has become overwhelming (the “mile-wide, inch-deep” problem). Faculty agreement on what is centrally important moves the conversation from what to eliminate to what supports core ideas.

There are also ideas that span disciplines—“crosscutting concepts,” such as cause and effect, conservation of energy and matter, and systems thinking. Energy itself is a core idea in each discipline, yet we rarely note the different ways disciplines treat energy, leaving students often unable to apply what they have learned in one discipline to another.

*H. Cooper and M. M. Cooper co-chair the Committee on Science Education.
Why evidence-based assessment?

Adopting evidence-based assessments has helped drive changes to instruction including pedagogy and curriculum.

If we can change the assessments, we can change the department.

- M.M. Cooper
Evidence-centered design

1. Domain Analysis
2. Domain Modeling
3. Conceptual Assessment Framework
4. Assessment Implementation
5. Assessment Delivery
Evidence-centered design

What are we planning to assess? In what contexts? And why? (Define domain)
Evidence-centered design

Domain Analysis

What are we planning to assess? In what contexts? And why? (Define domain)

Domain Modeling

How are key pieces of this domain going to be represented in assessment? (Develop arguments)

Conceptual Assessment Framework

Assessment Implementation

Assessment Delivery
Evidence-centered design

**Domain Analysis**
What are we planning to assess? In what contexts? And why? (Define domain)

**Domain Modeling**
How are key pieces of this domain going to be represented in assessment? (Develop arguments)

**Conceptual Assessment Framework**
What knowledge/skills do we expect? What evidence will be generated to evaluate them? (Align arguments with tasks)

**Assessment Implementation**

**Assessment Delivery**
Evidence-centered design

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What are we planning to assess? In what contexts? And why? (Define domain)

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How are key pieces of this domain going to be represented in assessment? (Develop arguments)

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What knowledge/skills do we expect? What evidence will be generated to evaluate them? (Align arguments with tasks)

**Assessment Implementation**
What does the assessment look like? How will it be scored? (Designing/testing the assessment tasks)

**Assessment Delivery**
Evidence-centered design

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**Assessment Implementation**
- What does the assessment look like? How will it be scored? (Designing/testing the assessment tasks)

**Assessment Delivery**
- What evidence is generated from these assessments tasks? (Use in classrooms)
Ok, but what do we focus on?!?
A marble is suspended at the top of a vacuum (no air) chamber.

When the marble is dropped and allowed to fall under the influence of gravity.

a. the marble falls at constant speed because there is no air inside.
b. the marble falls at constant speed because all falling objects do that.
c. the marble increases speed because there is no air in the way.
d. the marble increases speed because all falling objects do that.
e. none of the above are correct.
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'I like computation and I'm pretty good at it!

Max (he/him)
HOT TAKE
Assessing conceptual understanding is overrated
By focusing solely on assessing conceptual understanding, we miss many important pieces of a physics education.
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“Assessments will be needed for cognitive factors, affective factors, and career orientation. Cognitive assessments must consider both performance in the original integrated context and transfer of computational skills to additional science contexts…”
What can the community do?
Introductory physics lab instructors’ perspectives on measurement uncertainty

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Introductory physics lab courses serve as the starting point for students to learn and experience experimental physics at the undergraduate level. They often focus on measurement uncertainty, an essential topic for practicing physicists and a foundation for more advanced lab learning. As such, measurement uncertainty has been a focus when studying and improving introductory physics lab courses. There is a need for a research-based assessment explicitly focused on measurement uncertainty that captures the breadth of learning related to the topic, and that has been developed and documented in an evidence-centered way. In this work, we present the first step in the development of such an assessment, with the goal of establishing the breadth and depth of the domain of measurement uncertainty in introductory physics labs. We conducted and analyzed interviews with introductory physics lab instructors across the US, identifying prevalent concepts and practices related to measurement uncertainty, and their level of emphasis in introductory physics labs. We find that instructors discuss a range of measurement uncertainty topics beyond basic statistical ideas like mean and standard deviation, including those connected to modeling, another lab learning goal. We describe how these findings will be used in the subsequent development of the assessment, called the Survey Of Physics Reasoning On Uncertainty Concepts In Experiments (SPRUCE).

DOI: 10.1103/PhysRevPhysEducRes.17.010133
The PICUP community should help determine what is important to assess.
Instructors identify important concepts and practices

Pollard et al., PRPER, 2021
Instructors identify important contexts

Pollard et al., PRPER, 2021
What are the next steps?
What are the next steps?
Developing Assessment Arguments
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Developing Assessment Arguments

Assessment argument 1
Concept: Systematic uncertainty
Practice: Explaining choices
Activity: A basic measurement of volume
Physics theory knowledge: relationships between density, volume, mass
What are the next steps?

Developing Assessment Arguments

**Assessment argument 1**

**Concept:** Systematic uncertainty  
**Practice:** Explaining choices  
**Activity:** A basic measurement of volume  
**Physics theory knowledge:** relationships between density, volume, mass

**Task Idea:** A measurement of the volume of an irregularly-shaped object is needed to calculate its density in order to determine what material it is made of. These volume measurements can be done in several ways, such as by using string to measure length dimensions and then multiplying and adding to calculate a volume, or by immersing the object in water to measure the displacement. Each of these ways could introduce some systematic sources of error. Students will discuss which measurement approach is best for reducing systematic errors.
What are the next steps?
Developing Assessment Arguments

**Assessment argument 1**

**Concept:** Systematic uncertainty  
**Practice:** Explaining choices  
**Activity:** A basic measurement of volume  
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**Task Idea:** A measurement of the volume of an irregularly-shaped object is needed to calculate its density in order to determine what material it is made of. These volume measurements can be done in several ways, such as by using string to measure length dimensions and then multiplying and adding to calculate a volume, or by immersing the object in water to measure the displacement. Each of these ways could introduce some systematic sources of error. Students will discuss which measurement approach is best for reducing systematic errors.

**Rationale:** The context of measuring lengths and liquid volumes is relatively common and should be familiar to most students. This ensures the assessment argument targets measurement uncertainty concepts and practices rather than familiarity with the context. Asking students to make and explain their choice of technique for measuring volume requires students to be familiar with concepts of systematic uncertainty, as well as identifying sources of uncertainty.
Where are we now?
I'M INTERESTED

DC talking about assessment

PICUP Community
Physics computational literacy: An exploratory case study using computational essays

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(Received 9 October 2019; published 27 December 2019)

Computation is becoming an increasingly important part of physics education. However, there are currently few theories of learning that can be used to help explain and predict the unique challenges and affordances associated with computation in physics. In this study, we adapt the existing theory of computational literacy, which posits that computational learning can be divided into material, cognitive, and social aspects, to the context of undergraduate physics. Based on an exploratory study of undergraduate physics computational literacy, using a newly developed teaching tool known as a computational essay, we have identified a variety of student practices, knowledge, and beliefs across these three aspects of computational literacy. We illustrate these categories with data collected from students who engaged in an initial implementation of computational essays in a 3rd-semester electricity and magnetism class. We conclude by arguing that this framework can be used to theoretically diagnose student difficulties with computation, distinguish educational approaches that focus on material vs cognitive aspects of computational literacy, and highlight the benefits and limitations of open-ended projects like computational essays to student learning.

DOI: 10.1103/PhysRevPhysEducRes.15.020152
Physics computational literacy: An exploratory case study using computational essays

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3Department of Physics i

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DOI: 10.1103/PhysRevPhysEi

Investigating and improving student understanding of quantum mechanics in the context of single photon interference

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(Received 16 December 2015; published 14 April 2017)

Single photon experiments involving a Mach-Zehnder interferometer can illustrate the fundamental principles of quantum mechanics, e.g., the wave-particle duality of a single photon, single photon interference, and the probabilistic nature of quantum measurement involving single photons. These experiments explicitly make the connection between the abstract quantum theory and concrete laboratory settings and have the potential to help students develop a solid grasp of the foundational issues in quantum mechanics. Here we describe students’ conceptual difficulties with these topics in the context of Mach-Zehnder interferometer experiments with single photons and how the difficulties found in written surveys and individual interviews were used as a guide in the development of a Quantum Interactive Learning Tutorial (QuILT). The QuILT uses an inquiry-based approach to learning and takes into account the conceptual difficulties found via research to help upper-level undergraduate and graduate students learn about foundational quantum mechanics concepts using the concrete quantum optics context. It strives to help students learn the basics of quantum mechanics in the context of single photon experiment, develop the ability to apply fundamental quantum principles to experimental situations in quantum optics, and explore the differences between classical and quantum ideas in a concrete context. We discuss the findings from in-class evaluations suggesting that the QuILT was effective in helping students learn these abstract concepts.

DOI: 10.1103/PhysRevPhysEducRes.13.010117
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DOI: 10.1103/PhysRevPhysEd

Developing a learning goal framework for computational thinking in computationally integrated physics classrooms

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(Dated: May 18, 2021)

Computational thinking has been a recent focus of education research within the sciences. However, there is a dearth of scholarly literature on how best to teach and to assess this topic, especially in disciplinary science courses. Physics classes with computation integrated into the curriculum are a fitting setting for investigating computational thinking. In this paper, we lay the foundation for exploring computational thinking in introductory physics courses. First, we review relevant literature to synthesize a set of potential learning goals that students could engage in when working with computation. The computational thinking framework that we have developed features 14 practices contained within 6 different categories. We use in-class video data as existence proofs of the computational thinking practices proposed in our framework. In doing this work, we hope to provide ways for teachers to assess their students’ development of computational thinking, while also giving physics education researchers some guidance on how to study this topic in greater depth.
Developing Computational Assessments
Thank you!
Questions?

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