Implementing Research-Based Teaching in Your Classroom

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Contributors and Reviewers

☰ In this guide

This section provides guidance for classroom instructional staff on how to understand and implement research-based teaching in their physics classes. The section on Supporting Research-Based Teaching in Your Department provides guidance for department chairs and leaders on how to create departmental and cultural structures to support instructional staff in implementing research-based teaching in a department or program. Physics education research (PER) has produced many principles and strategies that can dramatically improve student learning of physics. We use the term *research-based teaching* broadly to refer to teaching that applies the principles of PER and/or uses strategies, tools, and/or materials developed through PER. Research-based teaching is structured around insights from research about students' physics ideas. It helps students build on these ideas through *active learning* or *interactive engagement*, in which students collaboratively think through physics rather than passively listen to lectures, as well as through peer interaction and formative assessment to support students in actively constructing their own understanding of physics. This section discusses teaching practices that improve learning of physics content and development of problem-solving skills; that support non-content goals including improving students' attitudes and beliefs about physics, science identities, and metacognition; and that support inclusive learning environments. For further guidance on incorporating these practices into specific classes, see the sections on Introductory Courses for STEM Majors, Introductory Courses for Life Sciences Majors, Courses for Non-STEM Majors, and Upper-Level Physics Curriculum. For guidance on using these practices to teach specific skills, see the sections on Instructional Laboratories and Experimental Skills, Computational Skills, and Communication Skills. For further guidance on creating inclusive learning environments, see the sections on Equity, Diversity, and Inclusion and Departmental Culture and Climate.

Benefits

Effective implementation of the principles and strategies described in this section has been demonstrated to improve student learning, satisfaction, and/or retention for all kinds of students, including students from marginalized groups, first-generation college students, introductory and advanced physics students majoring in physics and in other disciplines, and students who are underprepared. These practices support student learning and enable instructional staff to apply critical scientific skills in the classroom, engage in scholarship around teaching and learning, and be more productive, collaborative, and effective in their teaching. As a result, use of these practices can make teaching and learning physics more interesting and rewarding for both students and instructional staff.

The Cycle of Reflection and Action

Read this first

EP3 Glossary

Effective Practices

Practices

Effective Practices

Collapse all implementation strategies

1. Plan your approach to implementing research-based teaching in your classroom

A. Start small and approach teaching as a scientific problem

i. Recognize that you don't have to do everything. Pick a few ideas, principles, or strategies to try that make sense to you and fit with your teaching style, student population, departmental context, and classroom structure. Then, you can incorporate more ideas as you gain comfort and experience.

ii. Reflect on how you are already using research-based teaching, how you can improve what you are already doing, and what new approaches you might want to try.

iii. Choose a teaching goal to focus on each term, e.g., incorporate more group work, teach metacognition, or try a new set of materials.

iv. When you try new things in your classroom, assess the results to determine the extent to which they improve student learning and/or support other goals such as improving student attitudes and beliefs, and then adjust your approach based on the results of your assessment. See the section on How to Select and Use Various Assessment Methods in Your Program for guidance on how to assess student learning. Often, new approaches are not entirely successful when first used, but achieve better results as they are repeated and refined.

B. Get support

i. Find a group of instructional staff with whom you can discuss your teaching, whether in your department, your institution, or in the broader physics community.

ii. Find existing local resources through your department or your teaching and learning center, or national resources listed in Resources below.

iii. Don't reinvent the wheel. Use existing research-based and research-validated instructional materials whenever possible. See Resources below.

C. Use a process of backwards design

i. Think about what you want students to learn, and what evidence will show that they have learned it, before designing course activities. Design course activities to effectively help students learn what you want them to learn. Design assessments to assess what you want them to learn.

ii. See the Faculty Teaching Institute recommendation on What is "backwards design" and how can I use it in my physics classes? for details.

iii. See the section on Supporting Research-Based Teaching in your Department for guidance on how to use a cyclic process to design, assess, and improve courses based on student learning outcomes. This subsection will walk you through the steps of how to do backwards design.

2. Learn the general principles of research-based teaching

A.

Understand and apply the key recommendations from physics education research

i. When using any particular research-based instructional strategy, learn about the key features needed to make it work, while adapting other features as needed to your local context. See below for guidance on how to choose appropriate teaching practices for your context.

ii. Engage students in a variety of conceptual activities that require them to actively construct their own understanding, rather than to passively listen to lectures. Recognize that to deeply understand a concept, students must do the work of making sense of it for themselves.

iii. Provide regular, rapid feedback to students during in-class activities in which they communicate their ideas so that they can then revise them based on that feedback. This feedback may be provided by peers, instructional staff or instructional support staff, and/or technological means such as a classroom response system or simulation software.

iv. Provide opportunities for students to work in small groups, recognizing that learning is a social process and that students learn by collaboratively working out ideas with peers. See below for guidance on how to facilitate students working together effectively in small groups.

v. Build on students' pre-instruction thinking about physics and physics learning. Familiarize yourself with research on student thinking and specific student ideas, difficulties, and conceptual resources related to the topics you are teaching, e.g., the use of vectors, algebraic versus graphical representations, Newton's laws, or circuits. Design or implement instruction that builds on this research.

vi. Recognize that even after receiving relevant instruction and even when students can correctly apply mathematical problem-solving approaches, they often still give explanations of physical phenomena that contradict the most basic principles of physics. Even the strongest students do this, and there are good reasons for it. Expect this, and look for the reasoning behind students' explanations. Emphasize qualitative reasoning and conceptual thinking during in-class activities, homework, and assessments.

vii. Recognize that students do not necessarily lack sophisticated reasoning skills, but may lack an understanding of the proper contexts in which particular reasoning applies. Focus on identifying the reasoning skills your students are bringing to bear and helping them to redirect those skills to the proper context.

viii. Guide students to express their reasoning explicitly in diverse ways (e.g., verbally, in writing, and through small-group activities) and through multiple representations (e.g., text, equations, graphs, diagrams, pictures, and kinesthetic activities), in order to sharpen their thinking and support them in reflecting critically on their own and others' ideas. Recognize that deep understanding of an idea requires knowing it in multiple ways and through multiple representations.

ix. Use frequent low-stakes formative assessment to regularly learn about your students' ideas. Use a variety of assessment tools at different levels of cognitive complexity (e.g., application, analysis, and synthesis of knowledge) and use a spiral approach to presentation and assessment. Adjust your instruction based on what you learn from the assessments to meet students where they are.

x. Ground physics instruction in a wide variety of real-world physical systems that are relevant and interesting to students. See the section on Courses for Non-STEM Majors for guidance on how to choose course topics and activities that are relevant for your students.

xi. Explore the reasons and assumptions behind any simplifications or abstractions needed to make problems tractable or generalizable.

xii. Ensure that instructional materials and classroom activities incorporate both content, by building on knowledge of students' thinking, and process, by requiring active student engagement and reflection on their learning.

xiii. Build students' confidence and scaffold learning by breaking tasks into discrete steps and gradually reducing guidance.

xiv. Support students in organizing their knowledge into a coherent conceptual framework by focusing on how generalizing concepts can provide coherence and systematization to particular examples.

xv. Explicitly attend to students' motivation, beliefs in their abilities, beliefs about physics, and sense of belonging and identity in the physics classroom, recognizing that all of these factors shape their learning. See below for guidance on how to understand and implement practices that support different goals.

B. **Support students in understanding, buying into, and engaging in research-based teaching**

i. Read and implement the guidance in the PhysPort expert recommendation on How can I set clear expectations, and motivate students, so that they engage in active learning?. See Resources below.

ii. Set clear expectations for what kind of teaching practices will be used and what students will be expected to do, both on the first day of class and throughout the term.

iii. Discuss with students why you are using research-based teaching practices and how these practices can improve student learning. Discuss any results from local assessment data on the demonstrated positive effect that such practices have on student learning.

iv. Discuss with students how active learning may feel uncomfortable if it is not the kind of teaching they are used to. Discuss strategies they can use to thrive in your class, such as fully participating in activities, getting comfortable with not knowing the next step or answer, being prepared to work as a part of a team and to partner in the learning and teaching process, and coming to class prepared.

v. Acknowledge and address any discomfort students have with research-based teaching. For example, if students are uncomfortable that they are not being told the answer to a question, reassure them that the class will support them in figuring out the answer.

vi. Survey students early in the term about their perception of the research-based teaching practices in your class, publicize survey results to the class, and explicitly address concerns raised by students. It is often the case that most students appreciate these practices. Sometimes there is a small minority of students who complain, thinking they represent most students, but who will stop if they recognize that they are not speaking for the majority. See the section on How to Select and Use Various Assessment Methods in Your Program for guidance on how to use student feedback forms for formative assessment.

vii. Recognize that research-based teaching will be more effective if it is a part of the culture of your department as a whole, so that students become familiar with these practices and see them as a normal part of physics classes, rather than as an isolated activity that happens in one class. See the section on Supporting Research-Based Teaching in Your Department

C. **Create a welcoming classroom community**

i. Promote a vision of your classroom as a community where students work together towards common course goals and a shared framework of physics, and where all can be successful.

ii. Work to establish connections with students. Make a special effort to ensure that you are welcoming and nonjudgmental, especially if you are likely to be perceived by students as having a high degree of authority.

iii. Establish a classroom climate where all students feel safe participating and asking questions. Show respect to all students and address any disrespectful behavior from students towards other students.

iv. Establish positive and supportive classroom norms or community agreements (e.g., the STEP-UP Guidelines for Conduct During Discussions) collaboratively with your students, document these norms, and model them in class. An example of such a norm might be to critique ideas in a constructive way without doubting one's own or someone else's thinking abilities. Recognize that norms for argumentation in physics may seem overly confrontational to some students. To support students in understanding and questioning existing norms, have explicit discussions about argumentation norms in physics and other disciplines.

v. Encourage students to build ideas cooperatively and/or to co-design or co-create arguments that intentionally include a variety of perspectives, rather than focusing solely on individual argumentation.

vi. Regularly affirm students' ideas and contributions. This can help counter stereotype threat and the imposter phenomenon. Educate instructional support staff to do the same.

vii. Learn to be inclusive and culturally responsive, to focus on growth mindset approaches, and to recognize and explicitly address bias, microaggressions, and harassment in the classroom. Educate instructional support staff to do the same.

D. **Understand and implement inclusive teaching practices that support the diversity of students in your classes**

i. Learn about inclusive teaching practices that support all students to engage with the course and learn. For example, see Hogan and Sathy in Resources below.

ii. Draw from resources available on your own campus that support inclusive pedagogical practices, e.g., your teaching and learning center; your office of equity, diversity, and inclusion; and student-led equity groups such as the Access Network.

iii. See the section on Departmental Culture and Climate for guidance on how to ensure that your classes and curriculum create an inclusive and student-centered environment for all.

iv. See the section on Equity, Diversity, and Inclusion for guidance on how to ensure that your classes are equitable and inclusive.

v. Monitor what you, your instructional support staff, and your students are doing in the classroom to ensure that your teaching is equitable and inclusive, e.g., by using the Equity QUantified In Participation (EQUIP) classroom observation tool.

vi. Work to understand the kinds of support your students need to learn physics, which are likely to be different from what you needed when learning physics. Recognize that those who have become instructional staff in physics are those who have been most successful with the existing culture and teaching practices in physics, and therefore are atypical and not representative of the majority of physics students.

vii. Use diversity and differences among students in your classroom as an opportunity to bring many perspectives into your class through, e.g., activities that explicitly draw out students' different experiences, perspectives, and expertise.

viii. When planning a class activity or assignment, ask yourself who might be left out by the structure of this activity or assignment, and how it could be modified to be more inclusive of all students.

ix. Provide time for students to think and reflect on a question before asking them to answer or discuss it. Recognize that while some students may be comfortable immediately talking about a new idea, others may need time to think quietly before engaging.

x. Provide multiple ways for students to engage with questions during class, so that all students have the opportunity to engage with the material and share their thinking, not just those who are comfortable raising their hands and speaking in front of the class. For example, ask students to write down their answers to a question, discuss with their neighbors, and/or enter their answer in a classroom response system.

xi. Make the practices that help students learn an explicit part of your class, rather than something that students need to figure out on their own. Think about what students need to do to succeed in your class and build those things into class activities and assignments. Use class time, where support is available, to engage students in doing the most challenging work in the class.

xii. Identify and address the ways in which research-based teaching can have unexpected negative consequences for students from marginalized groups . For example, group work provides more opportunities for students to engage and learn, but also provides more opportunities for potentially harmful interactions. To make it more likely that students from marginalized groups have positive experiences during group work, see below for guidance on how to facilitate students working together effectively in small groups. To ensure that you learn about any negative impacts, provide ways to elicit students' voices, needs, and feedback, e.g., through student feedback forms for formative assessment, which are discussed in the section on How to Select and Use Various Assessment Methods in Your Program.

xiii. Communicate to students that everyone can learn physics.

xiv. Understand the range of backgrounds and preparation of students in your courses and consider how your course will provide all students the opportunity to succeed. Adopt strategies and techniques that include appropriate bridges to meet students where they are.

xv. Be adaptive to students' needs in class by, e.g., ensuring students have met a learning objective before moving on, revisiting content, incorporating

E. **Facilitate students working together effectively in small groups**

i. Read and implement the recommendations in the Guide to Effective and Inclusive Group Work and the PhysPort expert recommendation on How can I help students work well in small groups, so they are more likely to engage?. See Resources below.

ii. Assign challenging activities that give students a collaborative goal, require group work for success, support your course-level student learning outcomes, and are engaging and relevant to students. See the PhysPort expert recommendation on Where can I find good activities for small group discussions? for details.

iii. When possible, design physical classroom spaces that support group work. For example, seat students around small tables with moveable chairs, ample whiteboards, and space for the instructional team to reach all groups. See the section of The Physical Environment: Encouraging Collaboration and Learning for guidance on how to use current and future instructional spaces to promote active learning. When classroom redesign is not possible, do the best you can within the constraints of your classroom, e.g., by leaving an empty row between each row of students in a lecture hall so the instructional team can easily navigate to all groups.

iv. Provide a group workspace (e.g., a whiteboard, either fixed or portable) that is sufficiently large for all group members to contribute comfortably. Ensure that every group member has a writing implement. Design activities that support students in using this workspace to work out ideas either collaboratively or individually, make their ideas public so that peers can learn from them and provide feedback on them, and make their ideas visible to instructional staff and instructional support staff. See Best practices for whiteboarding in the physics classroom for details.

v. Determine whether to assign students to groups or allow them to select their own groups, weighing your goals with the pros and cons of each option. For example, self-selected groups may provide students more autonomy and support students from marginalized groups in ensuring they have a safe environment, while assigning groups may support students in learning to work with a wider diversity of people and may ensure that every student has a group. Research suggests that heterogeneous groups are more productive but it may be difficult for instructional staff to determine what makes a group heterogeneous. If you choose to assign groups, see the Guide to Effective and Inclusive Group Work for recommendations on how to do so effectively. Pay particular attention to ensuring that assigned groups are safe and welcoming for students from marginalized groups.

vi. Determine an appropriate size for student groups, recognizing that smaller groups are more effective for short-term simple tasks (e.g., clicker questions) and larger groups are more effective for long-term complex tasks (e.g., extended projects). Groups of three to four students work well for many small-group activities commonly used in physics classrooms.

vii. Determine how long groups will work together. Rotating groups every few weeks can give students sufficient time to develop good working relationships, while also providing students with practice working in different groups. If you rotate groups, tell students at the beginning of the term when, how, and why you will do this, so that students have time to prepare for this change and ask for any needed accommodations to ensure that they can work with their new group.

viii. Ensure that the instructional team has training on how to engage with groups effectively and how to notice and intervene if students are targeting or ignoring some group members.

ix. Work to ensure that students from marginalized groups are included and supported in full participation in group work by, e.g., explicitly discussing how systems of oppression (e.g., racism, misogyny, and ableism) may play out in group work, announcing that microaggressions will not be tolerated, and directly addressing microaggressions and bias when they occur.

x. Explicitly establish expectations for what students will do during group work, including the roles and responsibilities of each student and how students interact with each other. Encourage students to have pre-work discussions in their groups on the equitable division of labor and the importance of teamwork, as well as to rotate leadership opportunities within the group. Consider using group contracts to support students in developing norms and addressing inappropriate behavior from fellow group members.

xi. Ensure that all student voices are heard, and that no students dominate group discussions. For example, incorporate equitable participation into instructional team training, group contracts, group structures, and group norms. Create opportunities for all students to contribute.

xii. Consider assigning and rotating specific roles for each group member (e.g., facilitator, questioner/skeptic, reporter/scribe, and checker/reflector/summarizer) or supporting groups in determining the roles each member will play.

xiii. Ask students working in groups to write their names and pronouns where

3. Choose appropriate teaching practices for your context

A. Understand and implement practices appropriate for classes, laboratories, and recitations

i. Determine the strengths and constraints of each instructional setting, e.g., lecture, laboratory, and recitation. Use materials appropriate for each setting. Structure each setting so that all of the settings fit together to support student learning.

ii. In whole-class or "lecture" settings, use practices that emphasize active learning during class. Consider assigning reading and video lectures as homework in order to reserve classroom time for active learning activities when instructional staff, instructional support staff, and peers are available for discussion, feedback, and support.

iii. In recitations, use the opportunity of having a smaller class to engage students more deeply in active learning activities that involve extensive feedback and interaction.

iv. Structure laboratory experiences to teach the process of "doing science" rather than teaching more content. See the section on Instructional Laboratories and Experimental Skills for details.

v. Ensure that all parts of a course are connected and coherent, including lectures, laboratories, recitations, and homework. Regularly discuss connections between work done in different parts of the course.

vi. Consider using a SCALE-UP or studio classroom that integrates lecture, laboratory, and recitation together to create a more coherent experience for

B. **Address the needs of the particular population and level of your course**

i. Use research-based teaching in introductory and upper-level courses, and in courses for STEM majors and non-STEM majors. Use research-based curricular materials designed for each of these courses. Use PhysPort to find approaches and curricular materials particular to your course. See the Resources and Evidence in the sections listed in ii-v below for more resources particular to your course.

ii. In introductory courses for STEM majors, support students in developing an understanding of fundamental physics concepts, models, and practices and of how to use physics to analyze a multitude of situations within and outside of their majors. Ensure that these courses are welcoming gateways into physics and other STEM disciplines and that they do not become barriers to entry into any of these disciplines. See the section on Introductory Courses for STEM Majors for details.

iii. In upper-level courses for physics majors, emphasize conceptual reasoning and understanding and tie mathematical formalism to underlying physical phenomena. Provide opportunities for students to engage deeply with the discipline of physics and its excitement and challenges, to experience authentic physics practices, to build and strengthen their physics identity, to prepare for a diverse range of careers as well as post-graduate study, and to use in-depth disciplinary tools and concepts to critically engage with and solve problems in physics and society. See the section on Upper-Level Physics Curriculum for details.

iv. In introductory courses for life sciences majors, engage students in authentic applications of physics to issues in the life sciences and support them in developing an interdisciplinary conceptual framework and broadly applicable scientific competencies that will allow them to tackle complex scientific problems in their future work. See the section on Introductory Courses for Life Sciences Majors for details.

v. In courses for non-STEM majors, provide opportunities for students to do science, think like a physicist, and apply physics to things they care about and experience in their everyday lives, as well as to work in their own disciplines. See the section on Courses for Non-STEM Majors for details.

C. **Understand and implement practices that support different goals**

i. Set clear course-level student learning outcomes for each course, provide assessable learning outcomes with course syllabi, and design course activities and exams to be consistent with the stated learning objectives and each other. Consider outcomes based on goals for, e.g., physics content knowledge, conceptual understanding, problem-solving skills, scientific reasoning skills, metacognition, attitudes, beliefs, epistemology, and agency. See the section on Supporting Research-Based Teaching in Your Department for guidance on how to use a cyclic process to design, assess, and improve courses based on student learning outcomes.

ii. Articulate to yourself and to your students goals that might otherwise be implicit. Recognize that goals that are not stated clearly to students can create a hidden curriculum that impacts teaching and learning.

iii. Provide students with opportunities to give conceptual and qualitative explanations of phenomena and to connect these with mathematical explanations.

iv. Support students in developing problem-solving skills by providing opportunities to practice solving problems, both in small groups and individually, with scaffolding, e.g., by modeling problem solving, using explicit problem-solving frameworks, and/or supporting students to develop and describe their own problem-solving processes.

v. Design assignments and activities to foster student metacognition about learning and studying. Provide students with frequent opportunities to reflect on and discuss their own reasoning and problem-solving practices. For example, ask students to explain their reasoning and/or reflect on how they solved a problem, to reflect on what they have learned and what they are still confused about, to check results and test them against those obtained by student peers or resulting from an experiment, and to regularly ask themselves, “Does this make sense? What questions do I have about this material?” Emphasize that thinking about our thinking is part of doing physics.

vi. Prioritize opportunities for students to experience the joy of physics, gain an appreciation for its aesthetic beauty, apply it to things they care about and experience in their everyday lives, and learn about current research and applications of physics.

vii. Educate yourself on how physics classes can implicitly teach beliefs about the nature of physics and/or learning physics. See reference 3 in Evidence below. Design classes that support students in developing beliefs related to epistemology, model building, and ownership that are consistent with the practices of physics.

viii. Explicitly engage students in thinking about the different ways they might develop knowledge in physics, also known as epistemology. For example, ask students to reflect on the specific mechanisms they might be using in different situations to construct knowledge, such as “shopping for ideas, sense making, seeking coherence, restricting the scope, [and/or] choosing foothold ideas.” (Redish and Hammer 2009) Provide activities that support students in reflecting on specific examples for which their intuitions are both consistent and inconsistent with the rules of physics.

ix. Ask students to explicitly build and compare models to explain physical phenomena.

x. Support students in developing a sense of ownership over their own learning and authentic engagement in the practice of physics. Listen to student ideas, take them seriously, and build on them. Assign work that involves creativity, choice, and/or self-direction (e.g., investigative projects, topic essays, and design projects), with appropriate guidance.

xi. Identify and avoid practices that can implicitly teach beliefs that are inconsistent with the practices of physics. For example, drawing red boxes around equations may teach students that physics is about memorizing equations, covering too much material for students to think about the concepts deeply may teach them that they can’t understand the meaning of physics, and grading only for the right answer may teach students that the answer matters more than the process of getting there.

D.

Use particular methods, strategies, curricula, and tools developed through research

i. Use PhysPort to find and learn about these research-based methods, strategies, curricula, and tools.

ii. Implement conceptual questions that students discuss in small groups and answer during class (e.g., Peer Instruction, Think-Pair-Share, and Technology-Enhanced Formative Assessment) to support active engagement, discussion, and formative assessment.

iii. Implement technology-based classroom response methods (e.g, clickers or online polling systems where students can use their own computers or phones) or low-tech alternatives (e.g., colored cards or raising hands) to anonymously or semi-anonymously collect student responses to conceptual questions during class and gain real-time feedback about student learning.

iv. Provide opportunities for students to predict, explain, and discuss in-class demonstrations through, e.g., Interactive Lecture Demonstrations.

v. Implement alternative types of problems, e.g., context-rich problems, experiment problems, ranking tasks, real-world problems, thinking problems, and synthesis problems that combine multiple principles into a single problem. Choose problems that discourage practices such as "equation hunting" or "plug and chug" problem solving.

vi. Supplement instruction with scaffolded group activities that support students in developing their conceptual, mathematical, and/or epistemological understanding. Examples of research-based tutorials and worksheets that can be used in class or recitation sections include Tutorials in Introductory Physics, Activity-based Tutorials, Open Source Tutorials, and ACORN Physics Tutorials.

vii. Implement teaching approaches that support students in building models of physical phenomena by framing hypotheses, designing and carrying out experiments, testing hypotheses, interpreting data, and drawing conclusions. Examples of research-based curricula that support model building through experimentation include Investigative Science Learning Environment, Modeling Instruction, Next Generation Physics and Everyday Thinking, Scientific Community Labs, Workshop Physics, and RealTime Physics Active Learning Laboratories.

viii. Use research-based interactive simulations to enable students to easily conduct experiments, visualize the invisible, and explore physical phenomena. Examples include PhET Interactive Simulations, Physlets, and the Quantum Mechanics Visualization Project.

ix. Use pre-class assignments, modules, and/or quizzes to learn about students' ideas and questions and encourage them to prepare for class. This approach is also known as Just-in-Time Teaching.

x. Implement teaching approaches in which you "elicit and notice students' thinking; listen and attempt to understand students' ideas; and use those ideas to inform adjustments to the trajectory of a discussion, lesson, or semester plan" (Gouvea and Appleby 2022), such as Responsive Teaching.

xi. Consider the use of research-based instructional tools such as intelligent tutors, computer coaches, online homework systems, and AI systems, in which computers replace instructors. Recognize that such tools can increase student learning, but can also decrease student interactions with each other and with instructional staff and instructional support staff, and can sometimes provide misleading hints or guidance. Consider ways to use these tools to support students to learn how to ask questions and get support.

xii. Follow guidelines recommended by developers of research-based methods, strategies, curricula, and tools to ensure they are effective, while adapting them to your local context.

xiii. Partner with instructional support staff such as undergraduate instructional assistants, to support the use of research-based instructional practices. See the section on Supporting Research-Based Teaching in Your Department for guidance on how to engage students as instructional support staff to support research-based teaching.

4. Use research-based assessment practices

A. Align assessment practices with course goals

i. Ensure that each assessment you use provides information about something that will help you know whether you are achieving your course-level student learning outcomes and course goals, and that all course materials and activities are building skills that will be assessed. For example, if conceptual understanding and problem solving are goals, ensure that they are explicitly assessed.

ii. Ensure that exams and homework are an extension of the learning done in class and recognizable to students. Design homework to prepare students to do well on exams, and design both exams and homework so their content and structure are similar, and not surprising, to students.

iii. Align the distribution of course credit with the importance of activities for student learning. For example, give credit for pre-lecture readings and objective measures of in-class participation.

iv. Use a variety of question formats (e.g., multiple-choice, short answer, problem-solving, and essay) to assess different levels of cognitive complexity. Multiple-choice and short answer questions often assess lower levels of cognitive complexity, but can be written to assess higher levels. One way to do this is to present a paragraph, chart, or data and ask several questions about it that require not just factual understanding, but also interpretation and analysis.

v. Provide student credit for process rather than just outcome by evaluating students' written rationales for their decision making.

vi. Consider grading structures that explicitly incorporate collaboration, such as small-group projects, worksheets with individual and group deliverables, or two-stage exams. Consider awarding the same grade for a group assignment to every group member if one of your student learning outcomes is the ability to work effectively in groups.

vii. Consider using self-assessment or peer assessment (e.g., with rubrics) to help students develop metacognitive and evaluative skills.

B. Use assessment practices that support student learning and equity

i. Communicate to students early and throughout the term how you will assess their learning and the reasoning behind your assessment practices.

ii. Provide opportunities for students to practice and receive feedback without having their performance impact their final course grades. For example, use worksheets, in-class concept questions, peer grading, two-stage exams, or problems in which students use solutions to correct their own work. Grading some activities for participation rather than correctness or not grading them at all helps create a low-risk, low-stress environment and communicates that their purpose is to support student engagement and learning, and to assess student understanding to improve teaching, rather than to assign grades.

iii. Assign grades based on a fixed standard rather than relative to other students' performance, to encourage collaboration and mutual support and to assure students that their grades are based on their mastery of the material.

iv. Build in features that give students judgment-free flexibility to deal with life's difficulties. For example, provide multiple paths to earn a course grade by using a grading structure in which students do not need every point available to get a good grade and/or offer every student a single no-questions-asked extension.

v. Use multiple low-stakes assessments (e.g., quizzes, short and frequent exams, homework, projects, presentations, and discussions) with feedback throughout the term rather than a small number of high-stakes assessments.

vi. Consider using cumulative exams. Often, when exams are not cumulative, students cram and then forget their learning after the exam. Cumulative exams encourage students to continue building on prior knowledge throughout the course.

vii. Ensure that all timed assessments are short enough that all students can complete them in the time allotted.

viii. Complete each exam or homework assignment before giving it to students to ensure that the instructions are clear, that the problems are solvable, and that you can complete them in significantly less time than you expect them to take students. Consider also asking a colleague or instructional support staff member to work through them and check for clarity.

ix. Decide how and when to make homework, quiz, and exam solutions available to students. For example, wait to release solutions until students have had an opportunity to correct their work, provide scaffolding for students to create their own solutions, and/or use distribution mechanisms that discourage wide dissemination of solutions beyond the students currently in the course, e.g., an honor system and/or solutions posted inside a course management system in a format that is not easily downloadable.

x. After grading an exam or homework assignment, do a quick item analysis of the graded work. Are there particular questions that most students missed? Was the wording confusing? Was there another answer that could be interpreted as being correct? Use this information to guide grading and revision of future exams and homework.

xi. Use fair grading practices that minimize bias. Evaluate students on their knowledge and level of skill development or on objective measures of participation (e.g., answering a clicker question) rather than on subjective measures of participation (e.g., contributing to class discussion). Keep student identities anonymous while grading by asking students to use their student ID instead of their name or to only write their name or ID on the last page or the back of a page so that the grader doesn't see it while grading.

xii. Consider alternative grading structures for homework and exams such as using standards-based grading or allowing students opportunities to correct their work for full or partial credit.

xiii. Consider using rubrics when grading exams and homework problems where complex student performance is evaluated. Use of a rubric will help with consistency, especially when there are multiple graders. See the section on How to Select and Use Various Assessment Methods in Your Program for guidance on how to use rubrics of student performance.

xiv. Ensure consistent grading across all course sections, by, e.g., using coordinated questions and grading rubrics, setting common exam times or

Programmatic Assessments

Assessments

Programmatic Assessments

Collapse all assessments

1. **What are the mechanisms through which your program currently implements research-based teaching? What are the additional mechanisms through which it could do so?**

   A. Evaluate which of the above Effective Practices you are implementing and track the results of implementing them.

   B. Assess your teaching practices. See the section on How to Select and Use Various Assessment Methods in Your Program for guidance on how to assess teaching effectiveness.

2. **Are students learning in your class? How has student learning changed over time as you have modified your teaching?**

   A. Assess how effectively your teaching practices are impacting all aspects of student learning. See the section on How to Select and Use Various Assessment Methods in Your Program for guidance on how to assess student learning.

   B. Determine how your teaching practices are impacting student participation in physics by tracking attendance and participation in courses and DFW rates.

Resources

- The ComPADRE website includes a variety of resources for implementing research-based practices in physics classes including:
  - PhysPort: Resources based on physics education research that support teaching. Includes overviews of research-based teaching methods and materials, open-source curricula, expert recommendations, and assessments for introductory physics courses. Expert recommendations with more details on topics discussed in this section include What makes research-based teaching methods in physics work?, How can I help students

work well in small groups, so they are more likely to engage?, How can I set clear expectations, and motivate students, so that they engage in active learning?, and How do I develop student learning outcomes for physics courses?.

- The Physics Source: A collection of resources for introductory college-level physics courses. It includes curricula, curricular support materials, reference materials, and pedagogical and physics-education-research-inspired content and their research justifications.
- PER-Central: A resource collection for physics education researchers that includes articles, theses and dissertations, research groups, curricular material, and news and events. PER-Central is a great place to search for journal articles on specific physics education research topics.

- Physics and Astronomy Faculty Teaching Institute (FTI): A professional development program for physics and astronomy faculty focused on effective and inclusive teaching practice. The signature event is an intensive four-day professional development workshop offered twice annually by the American Association of Physics Teachers, American Physical Society, and American Astronomical Society. The FTI also includes an array of FTI long-term engagement activities. Previously known as the Workshop for New Faculty in Physics and Astronomy, or New Faculty Workshop (NFW).
- Overviews of research-based teaching in physics:
  - E. F. Redish, *Teaching Physics with the Physics Suite*, Wiley (2004): A book introducing physics instructional staff to the implications of physics education research, the cognitive basis for research-based teaching, and teaching methods and tools to improve physics instruction. Available as a free pdf from PhysPort.
  - R. D. Knight, *Five Easy Lessons: Strategies for Successful Physics Teaching*, Pearson Education (2004). A book introducing physics instructional staff to interactive teaching and the implications of physics education research, with examples of lessons, activities, and demonstrations for the physics classroom, and suggestions for teaching specific topics in physics.
  - A. B. Arons, *Teaching Introductory Physics*, Wiley(1996). A book with a comprehensive exploration of pedagogical issues in student learning of physics. Includes a detailed discussion of student physics learning problems and strategies for addressing these topic by topic, a collection of very challenging open-ended homework problems, and a guide to a nontraditional sequence in physics teaching.
  - J. P. Mestre and J. L. Docktor, *The Science of Learning Physics: Cognitive Strategies For Improving Instruction,* World Scientific (2020): A book introducing physics instructional staff to research on the teaching and learning of physics.
  - E. Mazur, *Peer Instruction: A User's Manual*, Prentice Hall (1997): A book introducing Peer Instruction, a method for integrating discussion of conceptual questions into lecture classes. Includes a large collection of questions for use in introductory physics courses.
- K. A. Hogan and V. Sathy, *Inclusive teaching: Strategies for promoting equity in the college classroom*, West Virginia University Press (2022).
- R. M. Felder and R. Brent, *Teaching and Learning STEM: A Practical Guide* (Jossey-Bass, 2016).
- M. W. Guthrie, X. Wu, and E. M. Scanlon, Guide to Effective and Inclusive Group Work (2022).

Evidence

The evidence in support of these practices comes from numerous sources, including physics education research articles published in Physical Review Physics Education Research, American Journal of Physics, The Physics Teacher, and various journals serving the discipline-based education research and education research communities. References 1–2 are meta-analyses of studies demonstrating the positive impact of research-based instructional practices on student learning in introductory physics courses and in STEM, respectively. Reference 3 is a meta-analysis of the impact of research-based teaching practices on students' attitudes and beliefs. References 4 provides an overview of research-based teaching methods and materials in physics. References 5–6 provide overviews of research-based assessment instruments in physics. Reference 7 provides an overview of the principles and practices that support learning based on research in cognitive science and educational psychology. Reference 8 is a synthesis study on the status, contributions, and future direction of discipline-based education research (DBER) in physics, the biological sciences, the geosciences, and chemistry.

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2. S. Freeman, S. L. Eddy, M. McDonough, M. K. Smith, N. Okoroafor, H. Jordt, and M. P. Wenderoth, "Active learning increases student performance in science, engineering, and mathematics," *Proceedings of the National Academy of Sciences* **111**(23), 8410-8415 (2014).
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5. A. Madsen, S. B. McKagan, and E. C. Sayre, "Resource Letter RBAI-1: Research-Based Assessment Instruments in Physics and Astronomy," American Journal of Physics **85** (4), 245 (2017).
6. A. Madsen, S. B. McKagan, E. C. Sayre, and C. A. Paul, "Resource Letter RBAI-2: Research-based assessment instruments: Beyond physics topics," American Journal of Physics **87** (5), 350 (2019).
7. S. A. Ambrose, M. W. Bridges, M. DiPietro, M. C. Lovett, and M. K. Norman, *How Learning Works: Seven Research-Based Principles for Smart Teaching* (Jossey-Bass, 2010).
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