PER User's Guide
Physics Education Research
Evidence-based resources for teaching physics

Guide

Tutorials in Introductory Physics

Indicates a research-demonstrated benefit

Overview

Guided-inquiry worksheets for small groups in recitation section of intro calculus-based physics. Instructors engage groups in Socratic dialogue.

Type of Method	Curriculum supplement, Tutorials
Level	**Designed for:** Intro College Calculus-based **Can be adapted for:** Intro College Algebra-based , High School
Setting	**Designed for:** Recitation/Discussion Session , Homework **Can be adapted for:** Lecture - Large (30+ students), Lecture - Small (<30 students), Lab
Coverage	Many topics with less depth
Topics	Mechanics, Electricity / Magnetism, Waves / Optics, Thermal / Statistical, Modern / Quantum
Instructor Effort	Medium
Resource Needs	TAs / LAs, Simple lab equipment, Cost for students, Tables for group work, minimal equipment for experiments, butcher paper or white boards at each table
Skills	**Designed for:** Conceptual understanding , Using multiple representations **Can be adapted for:** Problem-solving skills, Making real-world connections, Metacognition
Research Validation	**Based on research into:** theories of how students learn , student ideas about specific topics **Demonstrated to improve:** conceptual understanding , beliefs and attitudes , attendance , performance in subsequent classes **Studied using:** cycle of research and redevelopment , student interviews , classroom observations , analysis of written work , research at multiple institutions , research by multiple groups , peer-reviewed publication

Compatible Methods	Peer Instruction, PhET, JiTT, Ranking Tasks, ILDs, CGPS, Physlets, Context-Rich Problems, RealTime Physics, TIPERs, ABP Tutorials, SCALE-UP, OSP, SDI Labs, OST Tutorials, Thinking Problems, Workbook for Introductory Physics, LA Program, CAE TPS, MBL, CPU, SCL, TEFA, Tools for Scientific Thinking, Tutorials, Clickers
Similar Methods	ABP Tutorials, OST Tutorials, PBI, Lecture-Tutorials, QuILTs, Thermal Tutorials, Mechanics Tutorials, Tutorials
Developer(s)	Lillian C. McDermott, Peter S. Shaffer and the Physics Education Group at UW
Website	https://depts.washington.edu/uwpeg/tutorial
Intro Article	2692
Intro Article	Oersted Medal Lecture 2001: "Physics Education Research-The Key to Student Learning"

Essential features

Minimum Implementation:

- Students should work through one tutorial per week, during 50-60 minute class session, after the relevant topic has been covered in lecture
- Students should work on tutorials in small groups of 3-4Saul and Beichner 2001
- Each group should be given a large sheet of paper to write on and equipment
- Students should take pre-tests before each tutorial
- Pre-tests should not be graded for correctness
- Answers to pre-tests should not be posted and students should not be allowed to take them home.
- A copy of the pre-test should be posted in the tutorial classroom
- Exams should include qualitative conceptual questions
- Students should complete tutorial homework after tutorial
- Tutorials should not be graded but tutorial homework should be
- Tutorials should be staffed with TAs with an instructor/student ratio of 1/12
- TAs should respond to student questions with Socratic questioning, not with answers
- TAs should attend a weekly 60 minute prep session in which they take the pretest, work through the tutorial as if they were students, and review student responses to the pretest

Ideal Implementation:

- TAs should explain the theory behind tutorials to students, discussing why they work in groups and why the TAs answer with questions rather than answers
- TAs should actively encourage students to work together, and should intervene when a group is not interacting productively
- TAs should call out individual students who are not involved in group discussion, and make sure all members of the group understand what's going on, not just the most talkative
- TAs should check for agreement between group members and ask students to discuss a question further if they don't agree on the answer
- TAs should encourage students to use the large sheet of paper as a shared space for group problem-solving
- TAs should be instructed in how to effectively engage in Socratic dialog
- TAs should be instructed in how to effectively facilitate group interaction
- When students ask why they are required to do something in tutorial, TA responses should emphasize how the tutorial helps them learn, rather than merely the grading policy
- Tutorial sessions should be 90 minutes long
- As TAs work through tutorial in prep session, they should discuss places where students are likely to have difficulties and ways to help students with these difficulties. One way to do this is to have TAs role-play as students, and get other TAs to "help" them. Another way is to watch and discuss videos of students working through Tutorials
- TAs should be informed of why each tutorial emphasizes certain questions which may seem repetitive or unnecessary to an expert physicist without training in pedagogy
- TAs should be informed of places in each tutorial where students are known to get stuck, and questions that are known to be effective for helping them get unstuck. TAs should be encouraged to check in with each group to make sure they have correctly addressed the difficult spots in each tutorial
- TAs should explicitly ask students to reflect on their reasoning process with metacognitive questions such as, "What about this process helped you to figure out the answer?" or "What was this tutorial about?"
- TAs should tell students to introduce themselves to the other students at their table
- TAs should ensure that students do not leave the tutorial session early
- TAs should attend an additional weekly session on pedagogy in which they learn about education research and the theory of why tutorials work
- TAs should be told to paraphrase students questions back to them before responding
- The "social and environmental context" of the tutorials-including classroom, departmental, and institutional levels of implementation-should be structured to facilitate TA buy-in

References

- J. Saul and R. Beichner, An Activity-based Curriculum for Large Introductory Physics Classes: The SCALE-UP Project, presented at the Physics Education Research Conference 2001, Rochester, New York, 2001.

How to implement

- Students work together in small groups to get all students actively engaged and articulating their ideas about the physics concepts. Instructors should encourage student interaction.
- Asking students to predict the results of experiments helps them commit to an idea and therefore be more likely to remember if the results do not match their expectations.
- Instructors guide students to construct their understanding through Socratic questioning, rather than telling them the answers.
- Questions are based on research into student difficulties in physics.
- Materials are tested by student interviews and written tests of conceptual understanding, and revised in an iterative cycle based on research results.
- Questions focus on conceptual understanding rather than computation, helping students to understand the underlying models.

Common challenges

Addressing Common Obstacles to Implementation:

- ⊟ I teach only large lecture classes with no recitation sections.

  Ideally tutorials should be implemented in a smaller class setting with an instructor/student ratio of 12/1 or less. However, in some settings this is not possible. Some instructors have successfully implemented them in large lecture classes using clickers and whole-class discussions in place of small-group checkouts.

- ⊟ I don't have the resources to hire enough instructors.

  Ideally tutorials should be implemented in a smaller class setting with an instructor/student ratio of 12/1 or less. However, many institutions provide support for only one TA for a recitation section with 24 students or more. While many institutions have implemented tutorials with an instructor/student ratio of 24/1, this does not work as well. Instructors at these institutions report increased student frustration because they can't get enough help from TAs, and much lower learning gains on conceptual tests like the FCI and FMCE than at institutions with lower instructor/student ratios. One successful model for addressing this problem is to hire advanced undergraduates as instructors in addition to or instead of graduate TAs. Undergraduates are typically cheaper to hire than graduate students, and often more motivated to teach. Undergraduates can be hired in an informal manner, or as part of a formal program like the University of Colorado Learning Assistant Program. For the tutorial implementation to be sustainable in the long term, it is best to set up a formal program with a dedicated source of funding. Another model for addressing a lack of resources to hire instructors is for dedicated faculty members to volunteer to assist in teaching tutorials. While this works very well in the short term due to the increased knowledge and buy-in of the instructor, programs that use this model are not sustainable and tend to fall apart as soon as the dedicated faculty member leaves or wears out.

- Students don't finish the tutorials in the time allotted to them.

While tutorials are typically implemented in 50-minute recitation sections, the Instructor's Manual suggests that 90 minutes for a tutorial is ideal. It is not necessarily a problem if not all students finish the entire tutorial in class, as long most students finish most of it and the rest are able to work through it on their own at home and complete the tutorial homework. However, if many students are consistently completing less than half a tutorial in class and are struggling to complete the tutorial homework, the implementation should be changed. Instructors have found that non-science majors and students with weaker science backgrounds typically need more time, so in an algebra-based class it often works better to do one tutorial over the course of two weeks instead of in one week. Even if the time frame is longer, it works best to give students a clear time frame for completing the tutorial, rather than giving them an unlimited amount of time and only moving on to the next tutorial when everyone is done.

- TAs don't like the tutorials and/or don't teach them in the way they should be taught.

Instructor buy-in is an important issue in effective implementation of tutorials. TAs who don't believe in the teaching method will be much less effective at using it, and if students sense a lack of buy-in from their TAs, they will be much less likely to buy in to the method themselves. TA buy-in varies greatly among individual TAs and institutions, and research suggests that there are many factors that can affect buy-in.

- ⊟ Students don't like the tutorials and resist doing them.

Student resistance is an issue in nearly all institutions that use tutorials. This resistance is typically much worse during the first year of implementation, and it subsides in subsequent years as they become accepted as a normal part of instruction, but it never completely goes away. Even at the University of Washington, many students dislike the tutorials, even when they know that the tutorials help their learning. Professor Steven Pollock of the University of Colorado calls this the vegetable model of learning - students view tutorials as being like vegetables in that they know they are good for them, but don't like them. If you are thinking about implementing tutorials, you should expect some student resistance. However, there are things you can do to address and minimize this resistance.

There are three main reasons students give for disliking tutorials:

1. *Tutorials are condescending - they ask really basic questions over and over again.* Many students are turned off by the seemingly basic questions in the tutorials. Ironically, anecdotal reports suggest that honors students enjoy the tutorials more than other students, and physics graduate students can argue with each other over a "basic" tutorial question for hours. The reason for this is that these questions are usually not as basic as they seem, and these seemingly basic questions are usually getting at some very deep issue. The best way to address this objection is to talk to students about it explicitly, giving a few examples of seemingly basic questions and explaining how they are getting at deeper issues, and addressing it when it comes up. However, this can be difficult to do if you don't understand why a tutorial is asking a particular question.
2. *Tutorials make them feel stupid (because they keep eliciting the students' ideas and then showing them that they're wrong).* Tutorials use an "Elicit, Confront, Resolve" method of instruction in which incorrect beliefs about physics are elicited through carefully constructed questions that tend to bring out students' naïve ideas, confronted by helping students see the inconsistencies in their beliefs, and resolved by guiding students to find a new model that addresses the inconsistencies. While this method has been shown to be very effective at improving students' conceptual learning, it can have negative side effects in terms of students' attitudes towards physics. While stronger students may enjoy having their beliefs

challenged, weaker students may be frustrated by the experience of constantly having their incorrect beliefs exposed. Some students may "learn" from this experience that their intuition is always wrong and lack the confidence to work through physics problems. Some other teaching methods have been designed to address this problem, most notably Open Source Tutorials, which focus on pointing out the correct aspects of students' intuition and helping students redirect this intuition when necessary, and the Investigative Science Learning Environment, which focuses on helping students build scientific models using the processes that scientists use. However, research is still inconclusive about whether these methods are as effective for conceptual learning, or even for scientific thinking goals. Anecdotally, one thing that seems to help improve student attitudes within the context of tutorials is to be very explicit with students about the goals and methods of the tutorials, so that they understand what the tutorials are doing, as well as how and why.

3. *Please just tell me the answer and stop answering questions with questions.* By the time they get to college, most students have had many years of schooling in which they have been taught that the best way to learn is by listening to clear lectures from a teacher who is an authority. Research does not support this view, but we can't blame students for being more comfortable with more familiar methods of instruction. The best way to address this objection is for instructors and teaching assistants to be very explicit with students about why they are using this method of instruction. Talk to students regularly about the research showing that students do not learn much from traditional lectures and that they learn much more from active engagement methods such as tutorials. A great place to start is to refer students to the Tutorial FAQ page written by Steve Pollock.
4. *I work better individually, not in groups.* Many students dislike group work. There are two responses to this: One is again to point students to the research on group work. For example, a controlled study in which some tutorial sections were told to work individually and some were told to work in groups showed that students in the sections that worked in groups learned significantly more. The second response is to point out that most jobs require working in groups and this is a skill that employers value, so if they're not good at working in groups, they need to learn how.

- Students don't like the tutorials because they think the tutorials are condescending (because they ask so many seemingly basic and repetitive questions).
- Students don't like the tutorials because they say the tutorials make them feel stupid (because they keep eliciting the students' ideas and then showing them that they're wrong).
- Students don't like the tutorials because they want someone to just tell them the answer rather than engaging in Socratic dialog.
- ⊟ My colleagues don't think these will be as effective as traditional recitations.

  > Many physics faculty are skeptical about curricula that emphasize conceptual understanding rather than traditional problem-solving, believing that conceptual understanding is easier and/or less important than traditional problem-solving. However, research shows that students are often capable of solving traditional quantitative problems without a basic conceptual understanding of qualitative problems, and that focusing on conceptual understanding does not harm, and can improve, traditional problem-solving skills.

- ⊟ My students learn the content of the tutorials better, but don't learn how to ask themselves the kinds of questions that the tutorials ask, so their thinking skills are not improving.

  > While it is a stated goal of the tutorials to help students learn to question their own thinking, the research involved in their creation is targeted entirely at conceptual learning and no research has been done on whether they help achieve higher order thinking goals. Anecdotal evidence from experienced instructors suggests that tutorials do not help students achieve these goals, but that they do help *instructors*, including graduate teaching assistants and undergraduate learning assistants, achieve these goals.

- ⊟ Some students are demoralized by the tutorials, and seem to have "learned" that their intuition about physics is always wrong.

  > Tutorials use an "Elicit, Confront, Resolve" method of instruction in which incorrect beliefs about physics are elicited through carefully constructed questions that tend to bring out students' naïve ideas, confronted by helping students see the inconsistencies in their beliefs, and resolved by guiding students to find a new model that addresses the inconsistencies. While this method has been shown to be very effective at improving students' conceptual learning, it can have negative side effects in terms of students' attitudes towards physics. While stronger students may enjoy having their beliefs challenged, weaker students may be frustrated by the experience of constantly having their incorrect beliefs exposed.

Some students may "learn" from this experience that their intuition is always wrong and lack the confidence to work through physics problems. Some other teaching methods have been designed to address this problem, most notably Open Source Tutorials, which focus on pointing out the correct aspects of students' intuition and helping students redirect this intuition when necessary, and the Investigative Science Learning Environment, which focuses on helping students build scientific models using the processes that scientists use. However, research is still inconclusive about whether these methods are as effective for conceptual learning, or even for scientific thinking goals. Anecdotally, one thing that seems to help improve student attitudes within the context of tutorials is to be very explicit with students about the goals and methods of the tutorials, so that they understand what the tutorials are doing, as well as how and why.

Teaching materials

Tutorials in Introductory Physics come in a book published by Pearson. You can order them from Pearson Pearson or from Amazon. You can download a sample tutorial from PhysPort.