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

Guide

SCALE-UP

Indicates a research-demonstrated benefit

Overview

An integrated learning environment where the space is designed to facilitate interactions between small groups working on short, interesting tasks.

Type of Method	Classroom structure
Level	**Designed for:** Intro College Calculus-based, Intro College Algebra-based, Intro College Conceptual, Intermediate **Can be adapted for:** Teacher Prep Course, High School, Teacher Professional Development
Setting	**Designed for:** Studio
Coverage	Few topics with great depth, Many topics with less depth
Topics	Mechanics, Electricity / Magnetism, Waves / Optics, Thermal / Statistical, Modern / Quantum, Mathematical, Astronomy, Other Science
Instructor Effort	High
Resource Needs	Tables for group work, Studio classroom
Skills	**Designed for:** Conceptual understanding, Problem-solving skills, Lab skills, Using multiple representations, Designing experiments, Metacognition, Making real-world connections, working in groups
Research Validation	**Based on research into:** theories of how students learn **Demonstrated to improve:** conceptual understanding, problem-solving skills, lab skills, beliefs and attitudes, attendance, retention of students, success of underrepresented groups, 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, UW Tutorials, JiTT, Ranking Tasks, ILDs, CGPS, Physlets, Context-Rich Problems, RealTime Physics, Workshop Physics, TIPERs, ABP Tutorials, Modeling, OSP, SDI Labs, OST Tutorials, ISLE, Thinking Problems, Workbook for Introductory Physics, LA Program, PBI, PET, PSET, LEPS, CAE TPS, Astro Ranking Tasks, MBL, New Model Course, CPU, SCL, TEFA, CU Modern, CU E&M, CU QM, QuILTs, IQP, Thermal Tutorials, Mechanics Tutorials, Energy Project, SGSI, Paradigms, PUM, EiP, Tools for Scientific Thinking, PI QM, M&I, Tutorials, Clickers, MOP, Responsive Teaching
Similar Methods	Workshop Physics, EiP
Developer(s)	Robert Beichner
Website	http://scaleup.ncsu.edu/
Intro Article	4517
Intro Article	The Student-Centered Activities for Large Enrollment Undergraduate Programs (SCALE-UP) Project

What does it look like?

SCALE-UP

SCALE-UP is not a curriculum, but a physical classroom structure that encourages student interaction and discourages instructor lecturing. SCALE-UP classrooms often look more like a restaurant than a lecture hall. Students sit at special tables that each seat three groups of three students*, and there is no front of the classroom. Students have access to whiteboards, computers, internet, and lab equipment, and technology may allow the instructor to project student work onto screens around the room. There is no separate lecture, lab, and recitation; all of these activities are integrated into one setting. While there is no specific curriculum for SCALE-UP, activities should emphasize conceptual understanding and students working together. Having multiple groups at a table encourages students to interact not only within their groups, but also with other groups. Students are expected to read and master basic material before coming to class, so they spend class time working through problems rather than absorbing information. Students are trained to work effectively in groups, and are often assigned group roles to facilitate participation. Instructors monitor student understanding throughout class, and can flexibly change the pace or direction of class accordingly.

*There are also many variations of this arrangement, such as round, D-shaped or trapezoidal tables, with different numbers of groups and/or students at a table. For more details on variations, see Adapting to other environments.

Classroom Video

SCALE-UP/TILE at the University of Iowa:

Sample Materials

Below are some sample activities for SCALE-UP. You can find many more in the teaching materials section.

Examples of "Tangible" Activities

1. "Find the thickness of a single page from your textbook. Use this result to find the diameter of a period at the end of a sentence in the book." Students invariably start by dividing the estimated or measured thickness of a large stack of the pages by the number of sheets of paper in the stack. Although they usually don't think of it in these terms until prompted, the reason for using many sheets at once is to increase the number of significant digits in the final answer. In a Socratic dialog, students are asked questions about why they tackled the problem as they did. (This is often done by having them consider what answers they would have gotten from a different approach). By recognizing for themselves how significant figures play a role in measurement, they are much more likely to continue to consider the uncertainty in their measurements throughout the course.
2. "Find the coefficient of kinetic friction between your book and the table." Here the students slide their books across the table, estimating initial velocity and measuring stopping distance.
3. "Determine the angular acceleration of a rotating racquetball as it spins to a stop on your table." or "What is the impulse that the floor applies to a bouncing racquetball?" These

types of very brief activities help students build an intuitive understanding of otherwise abstract concepts.

4. “Find the number of excess charges on a piece of tape pulled off the table.” This exercise, adapted from Chabay and Sherwood’s textbook always prompts discussion as students compare the different answers written on the whiteboards surrounding the room.
5. “Use a laser pointer to determine the thickness of a single hair from your head” (or the spacing of the tracks on a CD). In what is essentially a mini-lab, students spend a few minutes deciding how they will approach the problem, making measurements, and sharing their results with others.

Examples of “Ponderable” Activities

1. “How many two-step paces is it across the US?” This activity is done the first day of class as an individual effort. After reporting the wide-ranging answers, students work in ad hoc groups to answer the same question. They are surprised to discover that the range of answers is much smaller, often within the same order of magnitude. This provides an opportunity to discuss the benefits of working in teams, as well as scientific notation, estimations, units, and standards. (The mile was originally defined as 1000 paces of a Roman Centurion.) Some students on their own initiative have started using route-mapping software on the Internet to make very accurate determinations of the distance.
2. “How far does a bowling ball travel down the lane before it stops skidding and is only rolling?” This is a very difficult problem and requires a lot of estimation. The insight students gain into what happens to the frictional force when skidding stops and pure rolling begins makes it worth the effort. An *Interactive Physics* simulation provided for the students gives them confidence in their answers.
3. “Design a car radio antenna optimized for your favorite FM station.” This type of activity makes it easy for students to see how physics is involved in their everyday lives. It certainly is not difficult to get students involved in the problem when they have a chance to debate the merits of different radio stations! Many students come back to class the next day having made a measurement on their car that verifies their earlier calculation.

What makes it unique?

How is SCALE-UP different from Studio, Tutorials, or other research-based teaching methods? SCALE-UP, like studio, is not a particular set of curricular materials, but a classroom structure that facilitates students working together. Many research-based teaching methods involve students working together in small groups. SCALE-UP created a model where these “best practices” (active and collaborative learning, etc.) could be used in large enrollment courses using the same resources as a traditional lecture course, partially by harnessing the power of technology. It can, and does, use adapted versions of other research-based materials.

One feature that differentiates SCALE-UP from other methods involving small group work is that students interact not only within their own small groups, but also with other groups, so that the entire classroom is a community where all the students are supporting each other. This inter-group interaction is facilitated through round tables with three groups of three students at each table, through activities that explicitly require students to interact with other groups, and through encouragement and instruction from the instructor. Because students are supporting each other through inter-group interaction and not just within their own groups, SCALE-UP can support much higher student/instructor ratios than other research-based teaching methods.

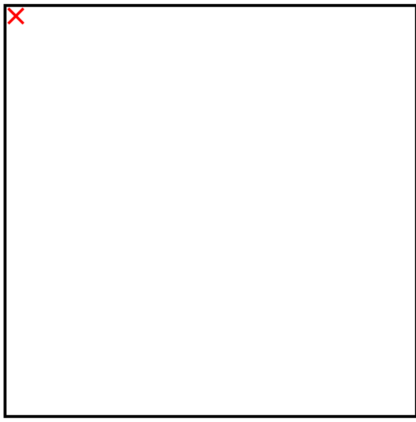
What makes it work?

SCALE-UP sets up a classroom structure that encourages all the features that make active learning work featured in our recommendation on What makes research-based teaching methods in physics work?

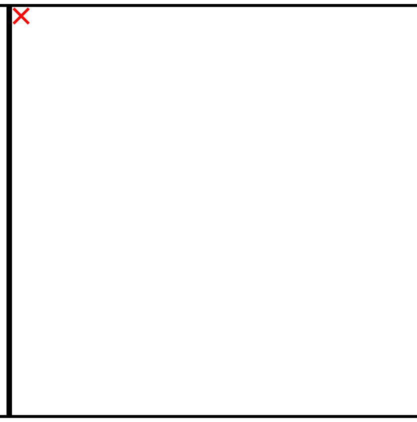
Where did it come from?

SCALE-UP was developed by Bob Beichner at North Carolina State University (NCSU) in order create a better way to teach large classes. In 1993 NCSU started a project called IMPEC (Integrated Math, Physics, Engineering, and Chemistry) that integrated physics, chemistry, mathematics, and introductory engineering science into an experimental one-year sequence of studio courses. The IMPEC classes were highly successful in minimizing attrition, improving student understanding of the course material and providing a positive learning experience for 36 students per year, but the project was suspended because it was impractical to expand the program to more than a small fraction of the thousands of students entering the NCSU Engineering program each year. The SCALE-UP project was started to apply the lessons learned from smaller studio classes to “scale up” studio instruction to a size that would be viable at large universities. The project’s main goal is to develop techniques and materials that permit use of research-based pedagogies in large-enrollment studio classes of up to 100 students, even though many of these materials were originally created for small class settings.

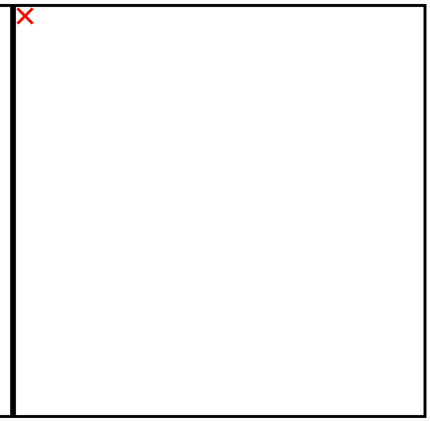
In developing SCALE-UP, Beichner and colleagues experimented with many different sizes and shapes of tables before settling on the 7-foot round tables that work best for large classes:



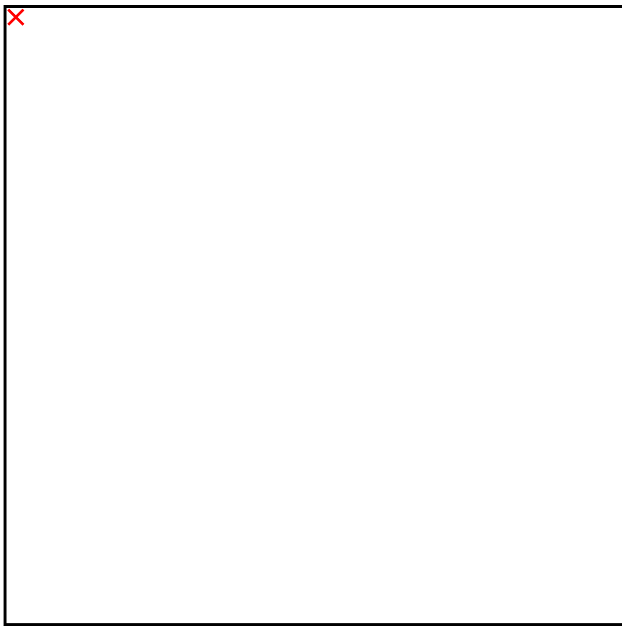
Generation 0: "Integrated" class of 36, 10-foot round tables



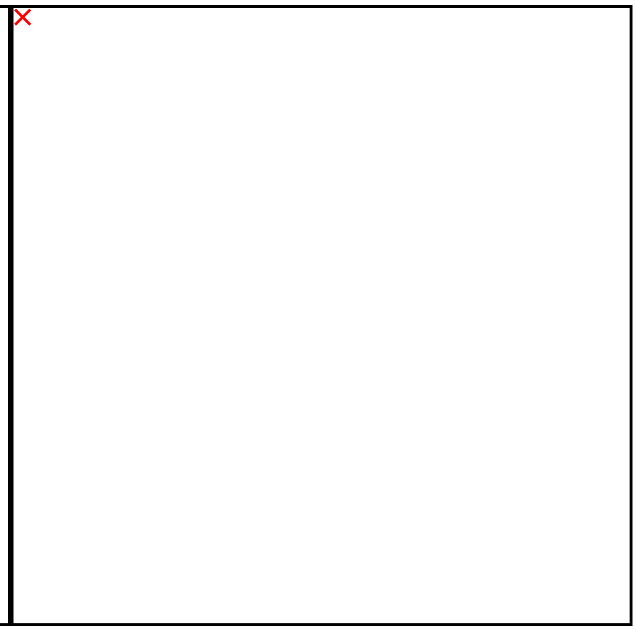
Generation 1: Lecture hall for 100, long rectangular tables



Generation 2: Special room for 54, 6-foot round tables



Generation 3: Special room for 99, 7-foot round tables



Generation 4: New room for 99 with whiteboards, screens, and microphones for every table, 7-foot round tables

SCALE-UP started as an approach for undergraduate physics classes at NCSU, but is now used in many different disciplines at hundreds of colleges and high schools throughout the world. SCALE-UP initially stood for *Student-Centered Activities for Large Enrollment University Physics*. When it expanded beyond physics, the name changed to *Student-Centered Activities for Large Enrollment Undergraduate Programs*. When it expanded beyond large enrollment classes, the name changed to *Student-Centered Active Learning Environment for Undergraduate Programs*. When it expanded beyond undergraduate programs to high school, the name changed again to *Student-C* *Student-Centered Active Learning Environment with Upside-down Pedagogies*.

Essential features

1) Special room that facilitates intra-group and inter-group collaboration

2) Students work in small groups and interact with other groups

3) Students acquire knowledge outside of class, and practice applying that knowledge in class

4) Instructor monitors understanding during class (and adjusts pacing accordingly)

5) Students solve real-world problems with an emphasis on conceptual understanding

6) Faculty, teaching assistants, and other instructors are supported in implementing principles 1-5 effectively

7) Principles 1-6 are institutionalized and implemented sustainably throughout a department or institution

What does the research say?

Research base behind the design of SCALE-UP

SCALE-UP was developed based on extensive research on the effectiveness of integrated learning environments such as Workshop Physics and Studio Physics (Wilson 1994, Hoellwarth et al. 2005), of research-based curricula for small group work in Physics (Meltzer and Thornton 2012) such as Tutorials in Introductory Physics and Context-Rich Problems, and of active learning methods (Johnson et al. 1981, Prince 2004) and social interaction (Astin 1994) in general. Before SCALE-UP, only small classes or recitation sections (typically less than 30 students) used curricula centered around students working in small groups on research-based activities. SCALE-UP was an attempt to "scale up" the successes of small integrated learning environments to classes of up to 100 students.

The structure of SCALE-UP also draws on results from Cooperative Group Problem-solving about how to structure and facilitate students working in small groups (Heller and Hollabaugh 1992), and Johnson, Johnson, and Smith's critical characteristics of successful cooperative learning: Positive interdependence, Individual accountability, Face-to-face interaction, Appropriate use of interpersonal skills, and Regular self-assessment of group functioning.

Research involved in the development of SCALE-UP

coming soon...

Research showing the effectiveness of SCALE-UP

coming soon...

Research on the use of SCALE-UP in different environments

coming soon...

References

- P. Heller and M. Hollabaugh, Teaching Problem Solving Through Cooperative Grouping. Part 2: Designing Problems and Structuring Groups, Am. J. Phys. **60** (7), 637 (1992).
- D. Meltzer and R. Thornton, Resource Letter ALIP–1: Active-Learning Instruction in Physics, Am. J. Phys. **80** (6), 478 (2012).
- J. Wilson, The CUPLE Physics Studio, Phys. Teach. **32** (9), 518 (1994).

How to implement

Coming soon... how to implement SCALE-UP

Common challenges

Challenges teaching with SCALE-UP in your course

How to frame it with students

Learning how to teach in a new setting

Developing materials to use in SCALE-UP classrooms

Unhappy students

Challenges institutionalizing SCALE-UP in your department

Getting adequate classroom space

Perception that it takes more instructor time

Instructor support: faculty, TAs, LAs

Getting administrative support

Getting funding

Lack of evidence of success

Integrating with other methods

SCALE-UP can be used in conjunction with nearly any research-based teaching method. Because

SCALE-UP is a learning environment rather than a curriculum, you can use any curriculum with it, as long as that curriculum is based on active learning in small groups.

Here are a few examples of **curricular materials from other teaching methods** that have been used successfully with SCALE-UP:

- Peer Instruction: Clicker questions make good ponderables for a SCALE-UP classroom.
- Tutorials: Tutorials in Introductory Physics, Activity-based Tutorials, and Open Source Tutorialscan be incorporated into a SCALE-UP classroom. Usually these require some modification with periodic whole-class check-ins to make sure all the groups are keeping up.
- Cooperative group problem-solving with Context-rich problems: This collection of problems for small groups from the University of Minnesota has been used in many SCALE-UP classrooms.
- Tasks Inspired by Physics Education Research and Ranking Task Exercises in Physics: These collections of short conceptual tasks work well for small group work in a SCALE-UP classroom.
- Thinking problems: This collection of problems from the University of Maryland are also great for small group work in a SCALE-UP classroom.
- PhET Interactive Simulations and Physlets: These and other simulations are designed for conceptual learning and can be used for small group activities or homework in SCALE-UP.
- Just In Time Teaching: Short questions that students answer outside of class are a good way to get students ready to participate actively in a SCALE-UP classroom.
- Microcomputer-based laboratories: Many SCALE-UP classrooms incorporate hands-on MBL activities.

Since SCALE-UP classrooms are often large and need extra instructors to help facilitate group work, many schools use a Learning Assistant Program to train undergraduate learning assistants to help out in the classroom.

See the lists of compatible methods and similar in the left sidebar for more ideas of other methods than can be used with SCALE-UP.

Adapting to other environments

The What does it look like? section describes the canonical implementation of SCALE-UP as originally envisioned by the developers. However, SCALE-UP is incredibly flexible and can be implemented in a wide variety of ways. This section describes some of the most common variations that uses different approaches to satisfy the essential features of SCALE-UP.

Beyond undergraduate physics

SCALE-UP originally stood for *Student-Centered Activities for Large Enrollment University Physics*. However, because it is now used in classes of all sizes in many disciplines at many levels, the name has officially be changed to *Student-Centered Active Learning Environment with Upside-down Pedagogies*, to be inclusive of the wide range of environments where SCALE-UP is now used.

Other disciplines: Because the design of SCALE-UP is not specific to physics, it can be used in nearly any discipline. SCALE-UP has been used in physics, chemistry, math, biology, astronomy, engineering, medicine, law, business, literature, political science, and many other disciplines. Other disciplines may need to adjust because they need to use more or less equipment than a typical physics class. Chemistry classes may not be able to have all parts of the class in the SCALE-UP room because labs need to be done in a room with a fume hood. Biology classes may need cabinets on the side walls so students can regularly access equipment. Teaching materials for SCALE-UP in other disciplines are available on theSCALE-UP members only site.

Small classes: SCALE-UP was initially designed to take the benefits of small studio classes into large enrollment classes. However, many of the innovations of SCALE-UP apply equally well to small classes and it is now used in a wide range of class sizes. As discussed in our recommendation on designing a SCALE-UP room, the large round tables that are typically used in large SCALE-UP classes may not be an effective use of space in a small classroom. Because there is more wall space per student and it is easy to see from one side of the room to the other, in small classes it may make more sense to use D-shaped tables with the flat side against the wall under a flat computer screen.

High school: SCALE-UP is also used in many high school classes. Many high school classrooms, especially those that already have lab tables, may be naturally more conducive to a studio format, so dramatic renovations might not even be necessary. When major changes to the structure of the classroom *are* involved, these changes are typically driven by the principal or superintendent, rather than an individual teacher. In addition to the adjustments for smaller classes discussed above, some modifications are needed for the different institutional environment and maturity level of the students. High school students typically know each other better, which may make it easier for them to feel comfortable working together, but harder to focus. Reading before class might be difficult for high school students because of high course loads, lack of independent study skills, etc. High school classes typically use shorter activities than college classes. Because high school teachers are trained in education, they typically need less help developing activities. High school teachers are often more explicit about helping students understand the structure of the class. For example, they might print out and laminate the different group roles, and always have each role sitting in the same place at the tables to help reinforce them.

Scaling down the technology, focusing on cheap physical infrastructure

Photo from Cornell University

Much of the expense of the ideal implementation comes from the technology: It is expensive to buy a laptop for every student and a system for projecting presentations and student work onto many screens around the room. While this technology can be nice, it isn't the most important part of SCALE-UP. Many implementers have found that they can get the most bang for their buck by focusing on outfitting a room with round tables and whiteboards and foregoing the technology. If you already have a room with large trapezoidal tables, you can create a SCALE-UP room at no cost by simply putting them together to form trapezoidal tables like in this classroom at Cornell.

Less-than ideal physical space

Ideally SCALE-UP should happen in a large room with 7-foot round tables that can fit 3 groups of 3 students, or a small room with D-shaped tables that fit 2 groups of 3 students. In either case, physical layout of the room should be such that students anywhere in the room can see anywhere else in the room, and there is no front of the classroom. However, not every institution has the physical space or money to create such a room. At the Central Washington University, students work in groups of 4 at tables created by putting three small desks together. At the University of North Carolina - Chapel Hill, they used an old lab room with long tables as a SCALE-UP room. Some schools implement SCALE-UP in lecture halls, in rooms that are too small to leave adequate space between tables, in L-shaped rooms, or in rooms with large columns that block the view from one side to another. Our recommendation on designing a SCALE-UP room discusses how to address these constraints.

Part-time SCALE-UP

Some universities aren't ready to go to SCALE-UP full time due to scheduling or other constraints, so they implement a hybrid model where some class time is scheduled in a SCALE-UP room and some is scheduled in a lecture hall. Ideally the time in the lecture hall should make use of interactive methods designed for large lecture environments such as Peer Instruction or Technology Enhanced Formative Assessment that intersperse lectures with short small group discussions. The time in the SCALE-UP room can focus on longer small group activities. This system is not ideal because it's difficult to make classes as interactive in lecture halls as in SCALE-UP rooms, and you lose the flexibility of having large blocks of time where you can easily change the next activity based on the issues that come up for students. However, it’s better than not implementing SCALE-UP at all.

Chemistry departments have found that they often need to have labs in a separate room due to the use of toxic chemicals and the need for fume hoods.

SCALE-UP by another name

Many institutions that have adopted SCALE-UP style classrooms and pedagogy use their own acronyms, such as MIT's TEAL (Technology-Enhanced Active Learning) and the University of Iowa's TILE (Transform Interact Learn Engage), or user other names such as studio (Boston University or Colorado School of Mines). Similar ideas have been developed under many names, and there is no recognizable difference between these approaches and SCALE-UP.

Case studies of successful adopters

Coming soon... case studies of successful adopters

Adopters

- Adopter A
- Adopter B
- Adopter C

Adopter A

Explanation

Adopter B

Explanation

Adopter C

Explanation

Teaching materials

Types of SCALE-UP activities with examples:

- **Class outline:** Because lab/lecture/tutorial sections are integrated, SCALE-UP class periods are typically long (~ 2 hrs), and filled with many short activities. To help students keep track of where they are in the class, the SCALE-UP developers recommend presenting an overview of each day's class on a web page that fits on a single computer screen and can be reviewed later. Example class outline

- **Tangibles:** These are short activities involving physical experiments using a predict-observe-explain model. Example tangibles
- **Ponderables:** These are short activities involving conceptual questions that students discuss and answer. Example ponderables
- **WebAssign activities:** You can use WebAssign or another content management system to assign problems in class that help reinforce concepts introduced in tangibles and ponderables, and helps you quickly assess whether students are understanding the concepts. These are typically short assignments that ask questions directly related to a tangible or ponderable activity the students just did. You can keep students from completing assignments before class by putting a password on the assignment that you give them in class. Example ponderable with follow-up WebAssign activity (unit vectors)
- **Labs:** In addition to short tangible experiments, students in SCALE-UP classes can also do longer experimental lab work that requires a formal report. Labs allow a focus not just on conceptual understanding but also on hypothesis generation, student design of data collection, and uncertainty considerations Example lab (impulse)
- **Real World Problems:** Problems like the University of Minnesota context-rich problems or the University of Maryland thinking problems are good ways to "give students challenging, realistic situations that are best analyzed by working in groups and following a problem-solving protocol" Example real world problems
- **3-way activities:** Each group at a table does a different type of activity on the same topic (useful for saving money/space on equipment - you only need one set of equipment for every 9 students, and while some students use equipment that takes up a lot of table space, other students can work on a laptop). Example 3-way activity (fancart)
- **Homework:** Homework in SCALE-UP should be used to cover the basics that you would normally address in a lecture so that students are fully prepared to participate in group work during class. This can be achieved through assigning reading with reading quizzes and a few straightforward problems before the class on a topic. Homework can also be used to assign more challenging follow-up problems after class. You can reduce grading through online homework systems and/or a "homework lottery" where you roll a die to decide which table's homework you will grade.

Download teaching materials for SCALE-UP classes from the members-only SCALE-UP site (you'll need to ask for a password), including:

- Physics Materials from NC State courses
    - Intro mechanics with Matter and Interactions
    - Intro E&M with Matter and Interactions
    - Modern Physics
    - Intro mechanics with traditional content coverage (VERY OLD)
    - Intro E&M with traditional content coverage (VERY OLD)
- The SCALE-UP Physics Library Project (under development)
- Spiral Physics (modeling) Materials from Monroe Community College

Other sources of SCALE-UP teaching materials:

- The University of Iowa has a collection of sample materials for their TILE/SCALE-UP classes in a variety of disciplines.
- The Massachusetts Institute of Technology has complete course materials for two TEAL/SCALE-UP classes: Introductory Physics I: Mechanics and Introductory Physics II: E&M

Find more example SCALE-UP activities in the following journal articles:

- V. Kuo and R Beichner, "Stars of the Big Dipper: A 3-D vector activity," The Physics Teacher 44 (4), 168-172 (2006). Get the activity described in the article
- M. B. Kustusch, J. D. H. Gaffney, and R. Beichner, "The Real Prize Inside: Learning about science and spectra from cereal boxes," Physics Teacher 47, 450-453 (2009). Get the activity described in the article
- J. D. H. Gaffney, E. Richards, M. B. Kustusch, L. Ding, and R. J. Beichner, "Scaling Up Educaton Reform," Journal of College Science Teaching 37(5), 48-53 (2008). Get the activity described in the article

Find many more **research-based activities that you can use in SCALE-UP classrooms** in our Expert Recommendation on finding activities for small group discussions.

Resources, training, & community

External Resources:

- SCALE-UP at Nottingham Trent University: NTU in the UK has produced extensive resources for implementing SCALE-UP, including a handbook for implementers and handouts for administrators, instructors, and students.
- SERC guide to SCALE-UP