ACTIVE LEARNING TEACHING FOR INTRODUCTORY PHYSICS

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KENT STATE UNIVERSITY

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Kolympari, Crete

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OR.....

• “It’s impossible to learn very much simply by sitting in a lecture...” Richard Feynman*

1. Introduction
2. Highlights of state of Science Technology Engineering and Math (STEM) Education (including PHYSICS) and Kent State Undergraduate Program
3. Research-Based curricula and Active Learning (AL) teaching
4. Active Learning Class for University Physics at Kent State
5. Conclusions/Comments
KSU Physics Department

- Kent State is the premier public University in Northeast Ohio
  - 41,200 undergraduate students
  - 6,500 graduate students
- Physics is a strongly-research-oriented Department
  - 20 tenure-track faculty, 2 full-time instructors
  - 80 undergraduate, 50 graduate students
- Physics research activity/productivity in recent years
  - \sim$3 M in research grants per year
  - \sim50 journal publications, 50 conference talks per year
- Physics is a top department in the US in terms of intro physics and astronomy enrollments per undergraduate student population
  - 3,500 Physics for Poets enrollments per year
  - 1,000 Introductory Astronomy enrollments per year
Professional Societies, and Science, Research, Business Panels or Commissions in the US urge strengthening of mathematics and science education. To name a few:

- American Physical Society
- National Research Council
  - Physics departments should review and revise their curricula to ensure that they are engaging and effective for a wide range of students and that they make connections to other important areas of science and technology.
  - Greater emphasis should also be placed on improving the preparation of high school teachers.
- National Science Board
- Committee for Economic Development
- National Academy of Sciences
• Science education is inextricably connected and vital to the long-term economic wealth, prosperity and national security.

• Reports of national committee of experts (academic, industrial and government) are extremely alarming regarding the state of undergraduate science education.

• Severe shortages are predicted in the scientific workforce in the next 5 to 10 years.

• Let’s see a short characteristic reminder:
REPORT TO THE PRESIDENT
ENGAGE TO EXCEL: PRODUCING ONE MILLION ADDITIONAL COLLEGE GRADUATES WITH DEGREES IN SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS

Executive Office of the President
President’s Council of Advisors on Science and Technology

FEBRUARY 2012

PCAST: Council of nation’s leading scientists and engineers appointed by the President
“Fewer than 40% of students who enter college intending to major in a STEM field complete a STEM degree. Increasing the retention of STEM majors from 40% to 50% would, alone, generate three quarters of the targeted 1 million additional STEM degrees over the next decade.”

“Based on extensive research about students’ choices, learning processes, and preparation, three imperatives underpin this report:
• Improve the first two years of STEM education in college.
• Provide all students with the tools to excel.
• Diversify pathways to STEM degrees.”
“PCAST Recommendation 1:

Catalyze widespread adoption of empirically validated teaching practices.

Learning theory, empirical evidence about how people learn, and assessment of outcomes in STEM class rooms all point to a need to improve teaching methods to enhance learning and student persistence. Classroom approaches that engage students in “active learning” improve retention of information and critical thinking skills, compared with a sole reliance on lecturing, and increase persistence of students in STEM majors. STEM faculty need to adopt teaching methods supported by evidence derived from experimental learning research as well as from learning assessment in STEM courses. Evidence based teaching methods have proven effective with a wide range of class sizes and increase learning outcomes even as enhancements of traditional lectures.”
Local Mandates/Motivation

• Ohio Governor’s Commission on Higher Education and the Economy (CHEE):
  • Increase number and proportion of Ohioans with mathematics and science knowledge, skills and degrees
• KSU Strategic Plan (2015) 1st Priority “Students First”:
  • 1:1 Enhance and expand student success programs system wide to improve retention and graduation rates
  • 1.2: Adopt a student engagement strategy that enhances learning through increased participation in high-impact experiences
  • 1.3: Align the undergraduate educational experience to focus on purposeful and essential learning outcomes
  • 1.4: Strengthen diversity and the cultural competence of students, faculty and staff system wide
• **Student retention, retention, retention…**
• Our most fundamental course sequence: University Physics
• Univ. Phys. DFW (D, Fail, Withdrawal) grades statistics:
  – DFW Univ. Phys. I: 47%
  – DFW Univ. Phys. II: 12% (data for Spring 2013 through Fall 2014)*

• **Graduating Majors**: Big concern (2000-2005, 3-4 /year), has improved (2006-2017, 8-12/year)

* Univ. Phys. Course Retention/Completion Committee
Department Level Motivation

• Student retention, retention, retention...

• Our most fundamental course sequence: University Physics

• University Physics DFW (D, Fail, Withdrawal) grades statistics:
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But above all, improve students’ conceptual understanding, problem solving and attitudes about learning (and the course)!!!!!
He entered Oberlin College in 1886, and took trigonometry, analytic geometry, and Greek—"the subjects which interested me most"—and a twelve-weeks' course in physics—"A complete loss." But, to his astonishment, he was asked to teach the physics course during his junior year. He prepared himself by working all the problems in the book that summer—and then making the students work them during the year. He became then, and remained all his life, a vigorous exponent of the problem method of teaching. The lecture method, he insisted, is "a stupid anachronism—a holdover from the pre-printing-press days." *

* “R. A. Millikan, Biographical Memoir” by L. A. Du Bridge and P. A. Epstein (1959), National Academy of Sciences
Millikan believed that large general lecture courses where ineffective...

Instead, he believed that “.... a collegiate course in which laboratory problems and assigned quiz problems carried the thread of the course could be made to yield much better training, at least in Physics......”

The idea was to make the whole course self-contained...**

This proposed approach has been the basis of the so-called studio or Workshop models for courses where lecturing in its traditional form plays a very small role.

** “Autobiography” by R. A. Millikan (1950)
Models of the Classroom

Two Major Classroom Curricula:

- **Traditional Instructor-Centered Environment**: focus of the class is the lecture

- **Active-Engagement Student-Centered Environment**: focus of class is what students are doing in class
Research-Based Curricula

Research and Redesign Wheel*

Curriculum Models

I. Lecture-based models
   • Traditional lecture
   • Peer Instruction/ConceptTests
   • Interactive Lecture Demonstrations
   • Just-in Time Teaching

II. Recitation-based models
   • Traditional recitation
   • Tutorials in Introductory Physics
   • Activity Based Physics Tutorials
   • Cooperative Group Problem Solving

III. Laboratory-based models
   • Traditional laboratory
   • RealTime Physics

IV. Workshop models
   • Physics by Inquiry
   • Workshop Physics
   • Explorations in Physics
Active Learning Environments Background

- **Physics by Inquiry (Pbl)**, developed and used by *Lillian Mc Dermott* and her collaborators at the University of Washington over the past 35 years for Physics teachers. It is the first modern application of Millikan’s connection of lab and lecture “to carry the thread of the course”.
  - In the Pbl class there is no lecture. There are laboratory manuals that guide the students into building the basic ideas of Physics.

- **Workshop Physics (WP)** method of teaching calculus based classes developed and used at Dickinson college by *Priscilla Laws* and collaborators in the 1980’s. Based on Physics by Inquiry, but including modern computer-based lab tools.
  - Students use an Activity Guide to go through the process of carrying out experiments and analyzing them.

- **Studio Physics**, developed at Rensselaer Polytechnic Institute (RPI) by *Jack Wilson* in the nineties. It was incorporated into the curriculum in 1994.

- **SCALE-UP** (Student-Centered Active Learning Environment with Upside-down Pedagogies) developed and used at North Carolina State University by *Robert Beichner* and collaborators in the nineties (started in 1995).

Will look more closely
• The SCALE-UP and Studio Physics approaches apply the Workshop Physics method of teaching to classes with a large number of students (50 and 99 respectively), while Workshop Physics is best suited for a smaller number of students (~ 25-30).

• Physics Education Research shows that learning achieved by students in the Active Learning Environment such as those listed is significantly greater than that achieved in courses taught in the traditional manner.
• Complete structural change from the traditional lecture/recitation/lab pattern.
• Class is structured into three (3) two-hour sessions, which take place in an appropriately organized “classroom” (learning facility).
• Method relies heavily on process of “scientific inquiry”.
• Class sessions include mainly making observations in small-group experiments and modeling of results, and whole class discussions, demonstrations, and some brief lecture segments.
• A four-volume Workshop Physics Activity guide is used.
• Classroom contains a special central area for common demonstrations and other group activities.
• Computers and a set of integrated computer tools and software are used for data acquisition, video capture and analysis and graphing and modeling.
“All the introductory physics have been taught in a Workshop format at Dickinson College since the 1987-88 academic year. Students meet in three two hour sessions each week. There are no formal lectures. The course content has been reduced by about 15% percent. Each section has one instructor, two undergraduate teaching assistants and up to twenty-four students. Each pair of students shares the use of a microcomputer and an extensive collection of scientific apparatus and other gadgets. Among other things, students pitch baseballs, whack bowling balls with rubber hammers, pull objects up inclined planes, attempt pirouettes, build electronic circuits, explore electrical unknowns, ignite paper with compressed gas and devise engine cycles using rubber bands. The Workshop labs are staffed during evening and weekend hours with undergraduate teaching assistants.”*

* physics.dickinson.edu
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lecture and lots of plug-and-chug homework problems may be dismayed by the amount of thinking involved. Students who have had high school physics may expect their physics to be math-dominated rather than experiment-dominated. And students who are unaccustomed to group work may have trouble interacting appropriately.

Workshop Physics is an attempt to seriously change the framework of learning to have students focus more strongly on understanding and on the experimental basis of the physics. Getting students to understand not just the physics but how to make this shift of mental frame can be difficult. Implementing a course like Workshop Physics effectively requires that the instructor be sensitive to all these complex issues and be aware of the need to renegotiate the instructor–student social contract.

**Figure 9.8** Error rates on the ECCE after traditional lecture (University of Oregon) and after Workshop Physics, before and after research-based modifications.

**Figure 9.9** Distribution of fractional gains on pre-post FCI* and FMCE** for Traditional Tutorial/CGPS and Workshop Physics.***

Based on the WP method but for large number of students.

Adopted by many institutions (over 300).

Class is structured into three (3) two-hour sessions, which take place in an appropriately organized learning facility “restaurant style”.

Students work with their assigned partners in groups of three on 7 ft diameter tables equipped with laptops.

Activities can be classified as tangibles, ponderables, visibles, and labs.

**Tangibles**: short activities (~10-15 min) that involve simple equipment for observations followed by discussion.

**Ponderables**: short activities on real world problems (thinking experiments), involve approximations and quick internet searches.

**Visibles**: activities using simulations

**Labs**: longer activities, hypothesis-driven may require a formal report.

SCALE-UP rooms facilitate Socratic pedagogy interactions of the Instructor and Teaching Assistants with the students.
In the midst of the action, three students, surrounded by whiteboards, work on interesting tasks while teachers coach. This approach is particularly effective in integrated classrooms like SCALE-UP, where social interactions between students and with their teachers appear to be the "active ingredient." The research base that supports the design of SCALE-UP makes the approach work, especially as more and more instruction is handled virtually via the web. Taking advantage of the relationships students build with each other and with their teachers becomes even more important. The most quoted study has been reported in hundreds of studies, and the fundamental approach of active, collaborative learning has been culled from many sources. The SCALE-UP environment: round tables seating three teams—"A," "B," and "C"—on activities, simulations, or interesting questions and problems. In science classes, this approach is not new, but its application to a place where student teams are given interesting things to investigate while the "C" groups could find the Fox News website to see how CNN covered the event. The "B" groups would read the Washington Post coverage, while the "A" groups at each table would go to the official's website to search for the least biased presentation, perhaps by an international organization like the BBC. Wheter the "lectures" are class-time or "tangibles" and "ponderables." Essentially, the SCALE-UP environment is a place where student teams are given interesting things to investigate while teachers coach and ask questions, send one team to help another, or ask why someone got a different answer. Even in a science course, there is no need for a separate lab. Most SCALE-UP classrooms: 7' diameter round tables, 11 tables of nine students—one laptop/team, one projection screen, and one laptop/team. The SCALE-UP scaleup.ncsu.edu SCALE-UP classooms: 7' diameter round tables, 11 tables of nine students—one laptop/team, one projection screen, and one laptop/team. The SCALE-UP scale up website: scaleup.ncsu.edu SCALE-UP classrooms: 7' diameter round tables, 11 tables of nine students—one laptop/team, one projection screen, and one laptop/team. The SCALE-UP scale up website: scaleup.ncsu.edu
1. Students should develop a good functional understanding of physics.
2. Students should begin developing expert-like problem solving skills.
3. Students should develop laboratory skills.
4. Students should develop technology skills.
5. Students should improve their communication, interpersonal, and questioning skills.
6. Students should retain and/or develop student cognitive attitudes and beliefs (expectations) that are favorable for learning physics with deep understanding.
Figure 4: Failure rate comparison for NCSU Physics I & II classes. Here, failing means receiving a grade lower than C – in the mechanics course or less than a D – in the E & M course, the grades needed to receive credit for taking the course. No Hispanic SCALE-UP students failed during the five years of data collection from 16,000+ students, so that bar is has zero length. Error bars represent standard error of the mean, and are mostly too small to be seen.

*http://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_072628.pdf

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Timeline of efforts at Physics Department

• Visits by experts: Edward Redish (2002). Beginning of efforts to revitalize undergraduate physics program
• First update/upgrade of University Physics Labs (~2003, acquisition of ~$160,000)
• Extensive effort to create an Active Learning Lab facility by joining the two Univ. Physics I and II rooms and the storage space in between them. (Proposals to acquire funds for the new Lab facility did not get approved…).
• 2009-2013: Smith Hall Renovation Committee formed….discussions with Architects…..Renovation delayed…. More discussions with Architects…..
• 2014: New Integrated Sciences Building will have an Active Learning Lab, discussions continue… Tremendous interest by many Departments…..
• It was finally decided that we will have our own Active Learning Lab space on the second floor of Smith Hall!
• Spring 2016: Visit of SCALE-UP expert Dr. R. Beichner, colloquium and workshop
• Active Learning Lab facility became ready in the Fall of 2016! An “impossible dream” finally came true!
Architects’ Smith Hall Lab Renovation Plan Dec. 2010

Phase 1: Remove walls/ doors separating Room 203, 205A, and 205B
Remove all utilities (gas, vacuum, water, plumb) from all areas except perimeter of open space created (Rooms 203, 205A, 205B)
Remove existing floor & replace with VCT - 10’ diameter circle in center of room, 4’ wide “corridor” E-W in center also.
Remove all tables, vanities, shelving, etc. from center of open area.
Install power and teledata for (14) workstations to be created along the perimeter of open space created (cabinet molded)
Recircuit lights.
Move existing tables to N, S, E, W perspective

Phase 2: Replace ceiling & lights throughout 205, 205A, 205B, 208
Remove wall separating 205 from 205A/205B & install accordion wall
Remove all utilities from center area of 205.
Remove existing floor & install VCT.
Remove tables from center of 205.
Install power and teledata for (10) workstations in 205 (S, W, N perimeter)
Recircuit lights

CC: J. Graham
A. Katramatou
G. Petratos
G. Putnam
G. Wilson

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New Active Learning (AL) Classroom Architects’ Drawing
AL Classroom Under Construction…
AL Classroom Under Construction…
and more Pictures...
First AL Teaching Fall of 2016

- Class met three times a week for 2 hours each time.
- Students sat in round tables in groups of three. Lecture part was very short. Students had to prepare for material ahead of time.
- Students worked on a variety of Active Learning activities, including large group activities.
- Many Lab activities mainly came from two-volume Lab workbook* modelled after Workshop Physics one.
- Professor and two Teaching Assistants (TAs) were always present in class together. There was strong professor-student and TA-student and student-student interaction.

**Tremendous preparation needed for first time material was used!!!!!!**

**Activity Examples**

- **Ponderables:** How many protons in a penny? How does a stud finder work?

- **Tangibles:** Connecting Capacitors, Investigating Flux concept, Laser pointer CD thickness investigation

- **Simulations:** Phet Simulations- Visualizing Electric Fields, Circuit investigation

- **Lab Activities** (longer activities): Metal Detectors, Spectrophotometer

- **Group Exercises:** Electric field of a uniformly charged rod
Activity Examples (cont)

Tangible: *Connecting Capacitors* activity

Large Group activity: *Spectrophotometer*
Sometimes we needed to be creative....
AL Classroom can have many uses...
Some Preliminary Findings

- Fall 2016: 21 students enrolled
- Only one D grade (no Fs or Ws) -> ~ 5% DFW (*but very low statistics!*) (Typical DFW rate was found to be 12%)
- DFW rate not a very objective metric!
- Used the Conceptual Survey of Electricity and Magnetism (CSEM)* assessment test:
  - Normalized gain $<g> = \frac{(\text{post} - \text{pre})}{(100 - \text{pre})} = 0.28$
- Not bad for first try but can be improved

Follow assessing process for University Physics II and then continue with University Physics I (Fall 2017).

**Interesting point:**
Taught University Physics I in the Spring of 2017 using the lecture-based format for the last time.

Took advantage of experience with AL teaching of Univ. Physics II and introduced as many AL aspects/activities in the teaching of Univ. Phys I as possible (limited by the time/space separation of Lecture – Lab.)

Very pleasantly surprised that the **DFW rate dropped approximately in half!**

But there is more…..
• Used the Force Concept Inventory (FCI) test: \( \langle g \rangle = 0.43 \)

• Even though the full method was not utilized, the test shows a big gain!

• Plan to use AL techniques everywhere possible!
• * Force Concept Inventory (FCI), D. Hestenes (Arizona State, AZ), M. Wells (Marcos De Niza High School, AZ), G. Swackhammer (Glenbrook North High School, IL), *The Physics Teacher* **30**, 141 (1992)

Can we answer the question: “What is the best way to teach a class?”

It may not be so easy because:

(a) There is no “one size fits all” method.
(b) There has been great progress in understanding Physics learning, but all we can do is provide guidelines to think about what may work for our students.
(c) Decisions on what to do are influenced by the particular goals to be achieved by one particular course.

**BUT we do know that applying AL teaching does make a difference!**
Some Final Words

• Let us use Amphi-theatres ….. for Theatre (as was the case in ancient Greece)….  
• and….. employ Socratic Pedagogy practices as was the case when teaching took place….  

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Aristotle Lyceum, Athens
• “Do not train children to learning by force or harshness, but direct them to it by what amuses their minds, so that you may be better able to discover with accuracy the peculiar bent of the genius of each.”  Plato, *The Republic*
Thank You!
BACK UP SLIDES
Electric Field from a Rod

A rod 8 cm long has a total charge of 12 μC distributed uniformly throughout it. Use the GOAL protocol to find the electric field at point P, which is 4 cm from the end of the rod.

Follow the strategy below for the A part of the GOAL protocol.

1. Start with a simple approximation, such as the charge is located at the mid point. What is E at point P for this situation?

2. Divide the rod in two and assume the charge is uniform. How much charge is on each half? Again assume a simple approximation that the charge is located in the middle of each half. What is E at point P?

3. Divide the rod into four equal pieces. Again, assume that the charge is located at the center of each piece. What is E?

4. Divide the rod into 8 pieces. What is E?

5. Estimate the electric field if you divided the rod into 100 pieces?

6. How does this compare with the "exact" answer? (Check your book!)

7. Compare your results with others groups at your table. Report one set of answers for your table.
A nonconducting rod of length $L$ has charge $-q$ uniformly distributed along its length.

(a) What is the electric field at point $P$, a distance $a$ from the end of the rod? (Do not insert a number for $k$ or $\varepsilon_0$.) Hint: break the rod up into sections of length $dx$. Find the charge $dq$ of the section $dx$.

(b) If $P$ were very far from the rod compared to $L$, the rod would look like a point charge. Show that your answer to (b) reduces to the electric field of a point charge for $a >> L$. 
Tangible T21_1: Made in the Shade

Shine a flashlight onto a card. Notice how the size of the shadow on your desk depends on the orientation of the card with respect to the beam of light. Can a formula for the flux like $$\Phi_E = EA \cos \theta$$ be used to describe how much light was being blocked by the card?

Each group needs: flashlight, small piece of cardboard, nail (2-3" with large head), protractor, ruler, meter stick

1. How do you define the orientation of a plane surface? Discuss with your group.
2. Make a drawing that shows how you could use a nail and a piece of cardboard to represent a unit of area. What angle should be used to define the orientation of the surface?
3. State which orientation of the nail and the beam of light represents 0°. Which represents 180°?
4. Hold the flashlight approximately one meter above the table and shine light from the flashlight down onto the cardboard held near the table.
5. Vary the angle of the cardboard and measure the area of the shadow on the table. Do this for ten angles between 0° and 180°. (Is there an easy way to measure the angle?) Which variables must you hold constant while taking these measurements?
6. Sketch a graph of the area of the shadow versus angle. The shadow indicates the amount of light flux, or the light intercepted by the cardboard. What mathematical model represents your results?
Tangible T21_1: Made in the Shade (cont.)

![Diagram](https://via.placeholder.com/150)

- flashlight
- nail
- cardboard
- shadow of cardboard

\[ \theta \]
www.peruseall.com*
*“The award-winning platform that ensures every student is prepared for every class
Order and assign textbooks, articles, or your PDFs in Perusall. Students annotate the readings and asynchronously respond to each other's comments and questions about the readings in context. With novel data analytics, Perusall automatically generates optimal student groupings and social interactions, grades students' engagement to ensure they are prepared for class, and nudges those who need help to keep everyone on track.”
The development of the CSEM began with the development of two separate tests on electricity and magnetism, originally called the Electric Concepts Inventory (ECI) and the Magnetism Concepts Inventory (MCI), which were tested in 1995-97. These tests were later renamed the Conceptual Survey of Electricity (CSE) and the Conceptual Survey for Magnetism (CSM), and combined to form the CSEM. (The latest version of the CSEM is version H, originally published in D. Maloney, T. O’Kuma, C. Hieggelke, & A. Van Heuvelen, 2001) D. Maloney, T. O’Kuma, C. Hieggelke, and A. Van Heuvelen, Surveying students' conceptual knowledge of electricity and magnetism, Am. J. Phys. 69 (S1), S12 (2001).

source: physport.org
The “Leaky Pipeline”

STEM Pipeline — Leaking Badly

In 2001, there were a bit more than 4 million 9th graders. Four years later, 2.8 million of them graduated and 1.9 million went on to two- or four-year college; only 1.3 million were actually ready for college work. Fewer than 300,000 are majoring in STEM fields and only about 167,000 are expected to be STEM college graduates by 2011.

Source: NCES Digest of Education Statistics; Science & Engineering indicators 2006
## SCALE-UP Objectives-Assessment

<table>
<thead>
<tr>
<th>NCSU SCALE-UP Objectives for Calculus-based Intro Physics</th>
<th>ABET 2000 Criterion 3: Program Outcome Requirements</th>
<th>Assessment Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCALE-UP students should:</td>
<td>Engineering programs must demonstrate their students have:</td>
<td></td>
</tr>
<tr>
<td>develop a good functional understanding of physics.</td>
<td>(3a) an ability to apply knowledge of mathematics, science, and engineering</td>
<td>Pre/Post concept tests on forces, graphs, electromagnetism, circuits</td>
</tr>
<tr>
<td>begin developing expert-like problem solving skills.</td>
<td>(3e) an ability to identify, formulate, and solve engineering problems</td>
<td>Student portfolios; interviews; test comparisons to control groups</td>
</tr>
<tr>
<td>develop laboratory skills.</td>
<td>(3b) an ability to design and conduct experiments, as well as to analyze and interpret data</td>
<td>Practical testing; student portfolios</td>
</tr>
<tr>
<td>develop technology skills.</td>
<td>(3k) an ability to use the techniques, skills, and modern tools necessary for engineering practice</td>
<td>In-class observations via field notes; practical testing; student portfolios</td>
</tr>
<tr>
<td>improve their communication, interpersonal, and questioning skills.</td>
<td>(3d) an ability to function on multi-disciplinary teams (3g) an ability to communicate effectively</td>
<td>In-class observations via field notes, audio, and video recording; interviews; focus groups</td>
</tr>
<tr>
<td>develop attitudes that are favorable for learning physics.</td>
<td>(3h) the broad education necessary to understand the impact of engineering solutions in a global and societal context (3i) a recognition of the need for, and an ability to engage in life-long learning</td>
<td>Maryland Physics Expectations (MPEX) survey; interviews; in-class observations via field notes</td>
</tr>
<tr>
<td>have a positive learning experience.</td>
<td>Not in the ABET criteria</td>
<td>Course evaluations; interviews; focus groups</td>
</tr>
</tbody>
</table>

Table 1: Overall objectives for NCSU SCALE-UP Physics and their relationship to the ABET criteria, which are indicated by (3a), (3b), etc. in the middle column. Pre-post concept tests were the FCI\textsuperscript{20}, FMCE\textsuperscript{21}, TUG-K\textsuperscript{33}, CSEM\textsuperscript{22}, BEMA\textsuperscript{13}, and DIRECT\textsuperscript{34}. MPEX stands for Maryland Physics Expectation Survey\textsuperscript{35}. 