更好的教育，更完善的生活

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The title of my presentation, “Better Education, Better Life”, is an obvious play on the theme “Better City, Better Life” of this year’s World Expo in Shanghai. It is intended as a reminder of the fact that investments in science and in particular in science education are the best possible way for a nation to ensure future economic growth, which leads to higher living standards for the entire population, hence a better life.

In this paper I will summarize our effort on updating our teaching methods and integration of communication technology (“the mechanics of teaching”). I will then focus on the importance of subject selection and coverage for the introductory physics curriculum (“the teaching of mechanics”)[1]. And I will finish with addressing the methodology of teaching creativity.

The Mechanics of Teaching

“*I think, however, that there isn’t any solution to this problem of education other than to realize that the best teaching can be done only when there is a direct individual relationship between a student and a good teacher […]. It is impossible to learn very much by simply sitting in a lecture […]. But in our modern times we have so many students to teach that we have to try to find some substitute for this ideal*.” Richard Feynman made these remarks in the introduction to his famous Feynman Lectures on Physics.[2] And it is safe to say that now, almost half a century later, not much has changed.

What can we do to transform large lecture classes into the more personal one-on-one experiences that Feynman identifies as essential to learning, if there is a constraint on the teaching budgets? Part of the answer may lie in the utilization of communication technologies, and here I will discuss how we are using audience feedback systems, “help rooms”, and in particular the LON-CAPA online course management and homework system.

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[1] W. Bauer and Gary Westfall, University Physics (McGraw-Hill, 2011)
[2] Richard P. Feynman, Robert B. Leighton, and Matthew Sands, The Feynman Lectures on Physics (Addison-Wesley, 1964)

Audience feedback systems, often simply referred to as "clickers", have been in use for more than a decade. They usually consist of one or more receivers attached to a host computer and individual input devices with 5 multiple-choice buttons for each student.[3] This technology is usually implemented wirelessly, either by using infrared or by using radio-frequency technology. In the future we would like to investigate ways to utilize cell-phones as input devices.

24.5 In-Class Exercise

For a circuit with three capacitors in series, the equivalent capacitance must always be

a) equal to the largest of the three individual capacitances.

b) equal to the smallest of the three individual capacitances.

c) larger than the largest of the three individual capacitances.

d) smaller than the smallest of the three individual capacitances.

Figure 1: Typical in-class test question used in conjunction with audience feedback systems. (From Bauer&Westfall, University Physics, with permission)

We use these audience feedback devices to ask approximately 3 to 7 questions in each lecture period. These questions serve multiple purposes. Trivially, the lecturer can take attendance and thus keep a record of who has shown up for which lecture. The questions also serve to break up a long lecture into multiple parts, which is essential when one realizes that the typical attention span, during which a student is able to fully concentrate on a lecture is on the order of 10 to 15 minutes. And these questions also force the students to think about concepts, which were introduced just previously, in a new context, and to give them meaning. An example is given in Figure 1.

Typically we ask these questions first with the request that individual students just enter their own opinion of the correct answer. Then we show the responses from the class (see Figure 2 for sample histograms). The next step is the most important one, because we then ask the students to discuss their solution with their neighbors, and we give everybody a chance to correct their answers.

Of the two histograms of student answers shown in Figure 2 the one to Question 2 is clearly preferable in our context. The reason is the distribution for Question 1 indicates that there is one answer, which is clearly right, whereas for Question 2 there are three answers that received a significant fraction of the votes, without any of them achieving a clear majority. Thus the case depicted on the right in Figure 2 yields a lot more intensive discussions than that on the left. It is important to try to construct questions, for which the

[3] We currently use iClicker (http://www.iclicker.com/), in no small part due to the fact that this system does not store student data offsite.

answers are not obvious, because they lead to much greater opportunity for intensive peer instruction.[4]

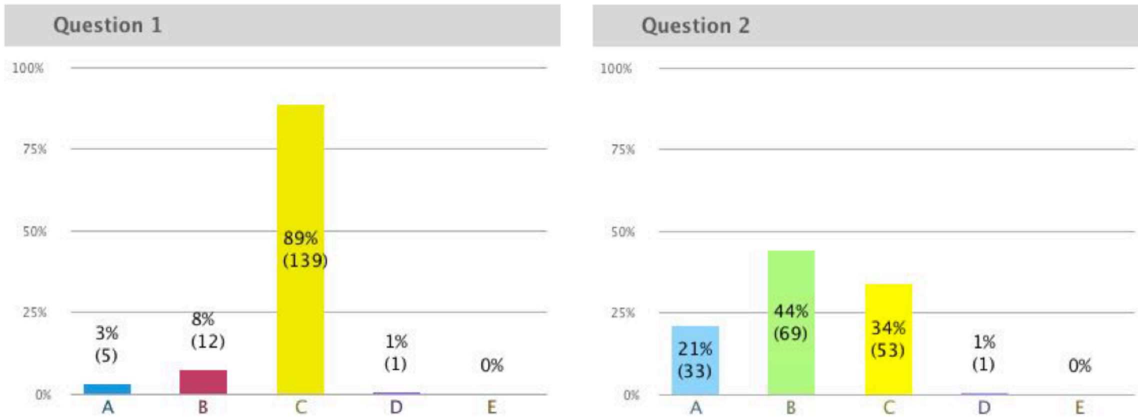

Figure 2: Two different histograms of student's answers to audience feedback questions.

A step towards one-on-one instruction of the kind envisioned by Feynman is the move towards smaller classrooms and student-centered learning environments. The SCALE UP (Student Centered Active Learning Environment for Undergraduate Programs)[5] approach at North Carolina State University has received wide attention and significant funding from the US NSF and US Department of Education. Recently, MIT has followed this instructional innovation. However, it is clear that significant faculty and teaching assistant resources are needed for this approach.[6]

At Michigan State University we believe that we have found a cost-effective way in which we combine the benefits of SCALE UP-like small classrooms with that of peer instruction through a teaching innovation, which we call the "help room". While we do not give up on large classroom instruction in the introductory physics sequence, we offer an honors option for student with a grade of above 3.0 (on a scale of 0 to 4, 4 being best), in which they sign up for shifts of helping their class mate in the help room. This help can consist of assisting in solving their homework problem, discussing the lectures, or understanding concepts. Typically 10% to 15% of the students sign up for this option, which enables us to keep help rooms open and staffed five days each week, typically from noon to 8 pm.

We believe that an in-depth understanding of concepts and mastery of physics can only arise from active participation and problem solving. This means that students have to solve homework problems, which is an integral part of the instruction process. But how does one grade on the order of 10 to 20 homework problems each week for on the order of 500 students in an introductory physics class? Even if one has the teaching assistants to perform this task, the typical turnaround time to return the graded homework

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[4] E. Mazur, Peer Instruction: A User's Manual (Prentice Hall, 1997)
[5] http://www.ncsu.edu/per/scaleup.html
[6] https://www.aapt.org/Programs/projects/spinup/spinup-regional.cfm

to the students would be a week, and by that time the students have moved on to working on other problems. Instant feedback is much more desirable.

A Michigan State University we have addressed this problem by creating the LON-CAPA (Learning Online Network with Computer-Assisted Personalized Approach) system.[7] It is a royalty-free open source distributed content management and assessment system, which since 1992 has its roots in the Multi-Media Physics[8] project, the CAPA project, and *lecture*Online. LON-CAPA is installed at over 100 institutions around the world, and it enables its users to share their resources with each other. This sharing feature is an essential component of the system, because it allows instructors to spend time creating just a few detailed and rich problems for everybody to use, while at the same time taking advantage of the work of others for the remainder of the problem sets needed for their courses.

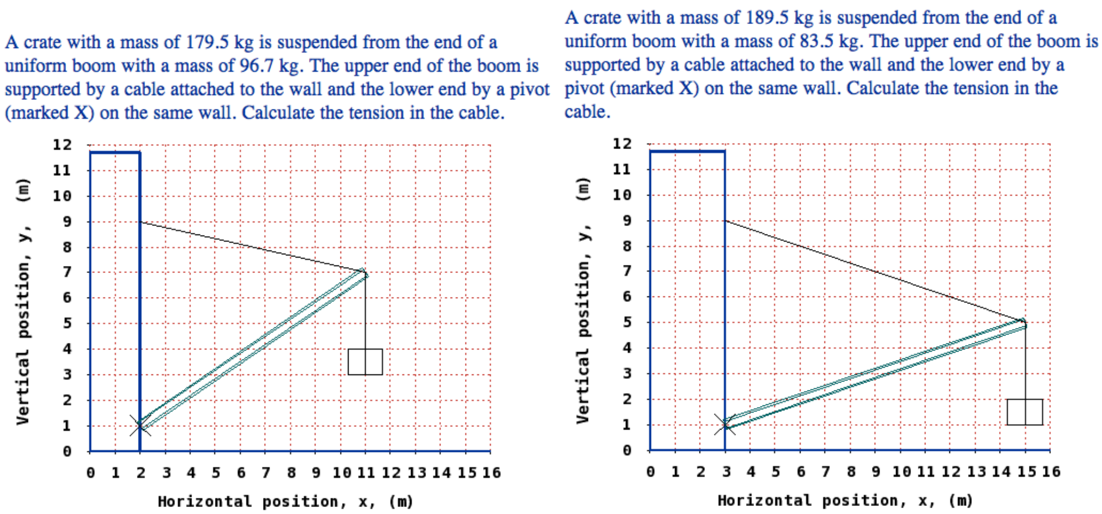

Figure 3: Sample of an individualized randomized problem as it appears to two different students.

One of the particular strengths of LON-CAPA is that it enables the coding of individualized randomized problems for students, which they are asked to answer on the computer. A huge variety of problems are coded in LON-CAPA.[9] The students are able to enter their answers to these problems into the computer, and the computer provides immediate feedback, with hints, if indicated. Depending on the instructor's preferred settings, answer tolerance, significant digits, and number of solution attempts can be adjusted, either globally or individually.

Since the problems are individualized and randomized for different students (see Figure 3), the students can, and are even encouraged to, work together on the solution. Since each student has a different set of numbers, a simple trivial copying of the solution

[7] http://www.lon-capa.org/
[8] http://www.pa.msu.edu/~bauer/mmp/
[9] For a selection of demonstration problems see: http://www.lon-capa.org/demo.html

is not possible.[10] Each attempt at solving a homework problem is automatically entered into a course grade book and at the same time provides effective and timely feedback to the instructor on the effectiveness of the instructional materials.[11] The same technology even enables us to give exams by using the same resources. We allow students to retake their exams online for partial credit within LON-CAPA.[12] This feature is very popular with students and very effective as an instructional tool.

We have included threaded discussion groups as a default option for all online homework problems, which enables students to discuss their conceptual difficulties and help each other in the solution. Some instructor moderation of these discussions is needed to make sure that overeager students do not simply give away the full solution, which would destroy the learning opportunity for their peers.[13] This mode of working together on problems is not just an effective means of peer instruction, but it also better prepares the students for future employment in their careers, where working in teams is the norm. A summary of our studies and experiences with LON-CAPA can be found in our 2008 paper in The American Journal of Physics.[14]

LON-CAPA is not the only toolset of its kind. We are utilizing others, such as WebAssign[15], as well. A particularly promising system is ConnectPlus from McGraw-Hill, which provides for an easy-to-use graphical interface and advanced drawing and grading tools.[16]

The Teaching of Mechanics

Applying physics education research to the way we teach our subject is essential, but alone it is not enough. We also need to ensure that students find our subject interesting, timely, and relevant to their own life experiences and the problems facing our society.

Physics is a dynamic field with an exciting and vibrant research enterprise that continues to produce stunning new results at an ever-increasing pace. Most of today's high-tech innovations, from GPS to cell phones, from computers to the Internet, from hybrid automobiles to medical imaging and treatment devices, are direct results of physics research. But in general, the field of physics as a whole has not done enough to

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[10] D.A. Kashy, G. Albertelli, W. Bauer, E. Kashy, and M. Thoennessen, Influence Of Non-Moderated And Moderated Discussion Sites On Student Success, *Journal of Asynchronous Learning Networks*, Vol. **7**, No. **1** (2003).

[11] G. Kortemeyer, M. Hall, J. Parker, B. Minaei-Bidgoli, G. Albertelli II, W. Bauer, and E. Kashy, Effective Feedback to the Instructor from Online Homework, *Journal of Asynchronous Learning Networks*, Vol. **9**, No. **2** (2005).

[12] G. Kortemeyer, W. Bauer, W. Benenson, and E. Kashy, Retaking a Test Online, *The Physics Teacher*, Vol. **44**, No. **4**, 235-239 (2006).

[13] G. Kortemeyer, Correlations between Student Discussion Behavior, Attitudes, and Learning, *Phys. Rev. ST Phys. Educ. Res.* **3**, 010101 (2007).

[14] G. Kortemeyer, E. Kashy, W. Benenson, and W. Bauer, Experiences using the open-source learning content management and assessment system LON-CAPA in introductory physics courses, *The American Journal of Physics*, Vol. **76**, 438-444 (2008).

[15] http://www.webassign.net/

[16] http://www.mhhe.com/bauerwestfall/

convey this to introductory physics students. Instead, when the introductory physics student opens the typical textbook during the first or second semester, it may seem that all of the interesting physics discoveries are centuries old. Chemistry, and in particular biology, have been much more successful to convey the excitement of cutting edge research to the beginner. This is one of the major reasons why biology is viewed as the science of the coming century, whereas physics is not.

In order to correct this and to allow introductory physics students to gain a deeper appreciation of physics as a cutting-edge science, we have taken great care to include examples from current research. We do not change the order of subjects covered, i.e. we do not start with "modern physics", because the conventional order of subject and concept coverage is based on a large body of physics education research, and because otherwise our introductory courses would not be compatible with other universities and credit would be impossible to transfer. However staying with the traditional sequence of subject coverage (mechanics, waves, thermal physics, electricity, magnetism, optics, quantum physics) does not mean that one has to wait until the end of this sequence to cover modern developments.

Modern research developments continue in all areas of physics. As an example, even in the first week of the first semester, when one covers the basics of the physical units, one can discuss current research into the precise definition of the base units and how to measure time, mass, length, and other elementary quantities precisely.

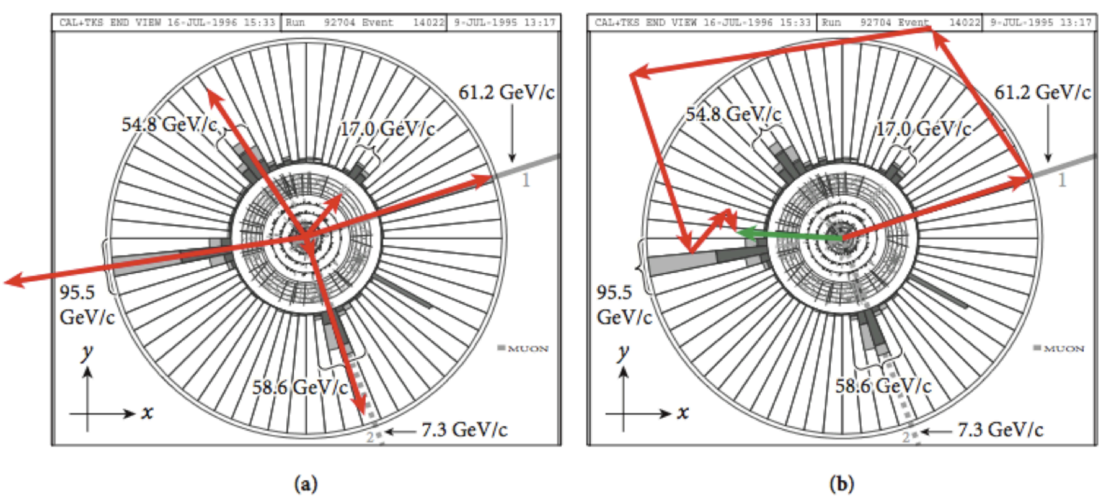

Figure 4: Example of inclusion of modern research – graphical vector addition in the discovery of the top quark by the D0 collaboration. (From Bauer&Westfall, University Physics, with permission).

A different example of inclusion of cutting-edge research results is shown in Figure 4, where momentum vector arrows from elementary particles produced in proton-antiproton collisions are added graphically to reveal the missing momentum vector of the neutrino produced in the decay of the top quark.

Another way to underline the importance of physics as a discipline is to discuss energy concepts in the introductory curriculum. We find that students are quite worried about future energy supplies and environmental consequences of our choices for our energy supply. To this end we discuss these energy related concepts wherever possible. One can, for example, discuss the sea level rise from global warming due to the thermal expansion of water. Or one can discuss energy transport via convection by studying the Gulf Stream, which carries thermal energy from the Caribbean along the Easter US sea border to Northern Europe. All of these problems can be reduced to a form, in which they can be conceptualized, discussed, and calculated with the instruments available to the first-year student.

Figure 5: Idealized Gulf Stream to discuss convection as a means of global energy transport. (From Bauer&Westfall, University Physics, with permission).

It is clear that physics concepts and knowledge will be essential to solve our global energy problems, to invent new technologies, and to evaluate costs and benefits of different energy supplies. It is of vital importance to teach these concepts to all students, and in particular to future leaders of our societies and countries. Examples, which can arise students' interest, are all around us. Figure 6, for instance, shows the super-cap bus, which runs on electrical energy stored in super-capacitors. Discussing examples like this one in the introductory curriculum may motivate some students to choose physics as a career.

Figure 6: Super-Cap bus in Shanghai, an example for use of advanced physics concepts in transportation.

Teaching Creativity

What is the primary goal of a basic physics education? It is not to accumulate and later recall facts. In the age of the Internet, of almost universal wireless connectivity, of Google, and of Wikipedia facts can be retrieved easily and almost without effort. Instead, what we really want to accomplish with a physics education is to equip our students with the ability to problem-solve. We need to install in our students the ability to examine a real-world situation, extract the relevant information, connect with known concepts, work out an algebraic solution where indicated, and finally arrive at an answer, hopefully with a known limit of confidence.

Becoming a problem-solver takes practice, just like mastery of any athletic discipline takes preparation and repetition. To this end it is important to expose our students to a wide range of conceptually rich and contextual problems, which is why weekly problem solving exercises are so important. But solving real-world problems can have a different dimension from solving textbook problems, because a solution may not exist, or because one may have to invent a solution method, which previously did not exist. How can we prepare our students for this challenge?

We think that the answer lies in exposing our students to real research experiences as soon as possible in the course of their studies. Admittedly, we cannot afford to avail all of our introductory students to these opportunities. However, we are able to do this for many or most of our physics majors. Many universities in the United States now have Research Experience for Undergraduates (REU) summer programs. These programs are funded by the US National Science Foundation and provide valuable exposure to current research problems for a large number of students, usually after their junior undergraduate year.[17] However, at Michigan State University we make research experiences available to a selected group of 100 entering freshmen each year. These students are called professorial assistants and receive monetary compensation for working in the research lab of a faculty supervisor. A significant fraction of these professorial assistants work on physics research, and some of our most successful physics and astronomy majors have taken part in this program and then continued with research projects throughout their undergraduate careers. Several of them have won prestigious national and international fellowships (Goldwater, Marshall, Gates, Rhodes, …), and many have gone on to successful graduate and postgraduate careers.

Summary

The two best methods to really learn a subject in significant depth are having to teach the subject and/or having to perform research on a subject. Conventionally, both of these constitute the typical work environment of a university professor. At Michigan State University we have attempted to make both, research and teaching, part of our undergraduate physics education experience. Our textbook (Bauer&Westfall, University Physics, McGraw-Hill, 2011) strives to achieve the same goal.

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[17] http://www.nsf.gov/home/crssprgm/reu/