New Ways for Physics Education

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This article introduces Physics Education Research (PER), which focuses on the connection of teaching and research. A modern pioneer in this field is David Hestenes.[1] He defines five principles of (conceptual) learning:

P1. Conceptual learning is a creative act.

P2. Conceptual learning is systematic.

P3. Conceptual learning depends on context.

P4. The quality of learning is critically dependent on conceptual tools at the learners command.

P5. Expert learning requires deliberate practice with critical feedback.

I will explain these principles and give an overview of practice and experience with conceptual learning of physics in the last two decades.

As for P1, Piaget said: "To understand is to invent." The creative powers of individual students are very important. A student works with more hints, than the first scientist, who invents a new theory. But a student repeats the basic scientific discovery by rewriting the codebook of his experience. P2 means that concepts are part of a coherent conceptual system. Concepts should not simply be studied one by one, but in a coordinated approach with related concepts. An example is the coordinated teaching of Newton's laws. The social and intellectual context (P3) of conceptual learning needs careful consideration. The environment for scientific research is important for researchers. In the same way an optimized classroom environment is necessary for the learning of specific concepts. The conceptual tools (P4) of the students have to be carefully devised. An especially important tool for learning physics is mathematics. Here a diversity of overlapping mathematical languages is to be avoided. A unified approach for teaching mathematics to physicists on all levels and for all areas of physics is available[1] and needs to be implemented. Practice without critical feedback (P5) and deliberate attempts to improve, does not substantially raise intellectual performance. Especially rote learning, which is common for Japanese university entrance examinations fails this criterion.

How is knowledge constructed? Modeling Theory (D. Hestenes and collaborators) states that "scientific knowledge is created, first, by constructing and validating models to represent structure in real objects and processes, and second, by organizing models into theories structured by scientific laws."[1] Models are basic units of scientific knowledge, and creating and validating models (modeling) is the basic way of learning. A Model Theory based reform of physics teaching has been carried out extensively on high school and university levels over the past two decades in the USA, supported by the US National Science Foundation. Modeling Theory shows that traditional physics curricula are seriously in need of reform at all levels (school through to university). Students (and textbooks) need to learn to distinguish between models and their implications in order to avoid cascades of learning difficulties.

Aiming at physics high school educators, a sequence of workshops "Modeling Instruction in High School Physics" is carried out in the US.[2] The basic idea is learning through a two stage modeling cycle. Stage 1 is model development with exploration and invention sub-stages. Stage 1 includes the specification of a model to represent it conceptually, and an evaluation of the fidelity of the representation. Stage 2 is model deployment in a variety of physical situations. Stage 2 corresponds to the discovery stage of new scientific knowledge.

To scientifically evaluate the success of these new methods a Force Concept Inventory (FCI), a Mechanics Baseline Test (MBT), a Views About Science Survey (VASS) and related literature are available.[3] These evaluation tools are available for download to authorized educators, some in a variety of languages. The FCI requires a forced choice between Newtonian concepts and commonsense alternatives. At first glance the questions may seem trivial. But many professors are shocked by the bad performance of their students. The MBT assesses most basic concepts in mechanics, which should be taught in introductory physics at any level. It looks like a conventional quantitative, problem-solving test, though it mainly assesses qualitative understanding. The VASS has the general purpose to survey student views about knowing and learning science and assess their relation to student understanding.

For university level physics teaching an NSF supported workshop program "Remodeling University Physics" is operating in the US.[4] Further components of the physics education reform in the US are graduate programs for high school physics teachers, local physics alliances (learning communities for physics teachers) and university-high school partnerships for sustained scientific education reforms.

[1] D. Hestenes, Oersted Medal Lecture 2002
http://modelingnts.la.asu.edu/pdf/OerstedMedalLecture.pdf

[2] Modelling Instruction in High School Physics
http://modeling.la.asu.edu/modeling-HS.html

[3] Research and Evaluation http://modeling.la.asu.edu/R&E/Research.html

[4] Remodeling University Physics http://modeling.la.asu.edu/rup_workshop/