"A novel methodology for measuring content knowledge in physics"

http://www.cognisity.how/2018/04/MOCC.html

Dr. Valentin Voroshilov

Professional experience and areas of expertise:

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Algebra based physics
Calculus based physics
Physics for science teachers
Physics for students with learning disabilities
Algebra
Geometry
Trigonometry
Methods for teaching physics

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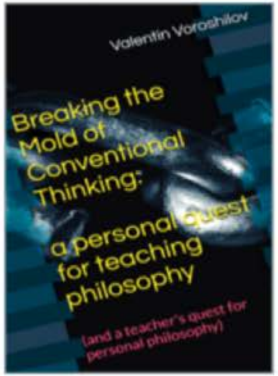

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Thinking about becoming a STEM teacher?
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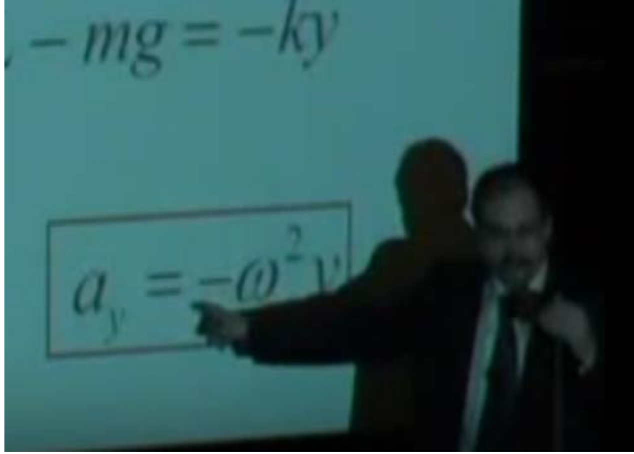
How I flipped my class without even knowin

Hello,
I am Dr. Valentin Voroshilov. I was born and grew up in Russia. I haven't had a formal education in English. When I speak my pronunciation might be off key. That is why I have supplied the slides with narrations which were scientifically prepared to minimize misunderstanding.

I would like to start my presentation from two statements: Physics is a science. Teaching physics is not. Of course, these statements are based on a certain definition of “science”.

Physics is a science.



Teaching physics is *not*.

Personally, I don't like descriptive definitions like the one on the left. In fact, such a definition does not really allow to distinguish a science from a religion. I prefer operational (prescriptive) definitions, like the one on the right. In particular, this definition allows us to see when a school of thoughts becomes a science.

"Science"

A descriptive definition

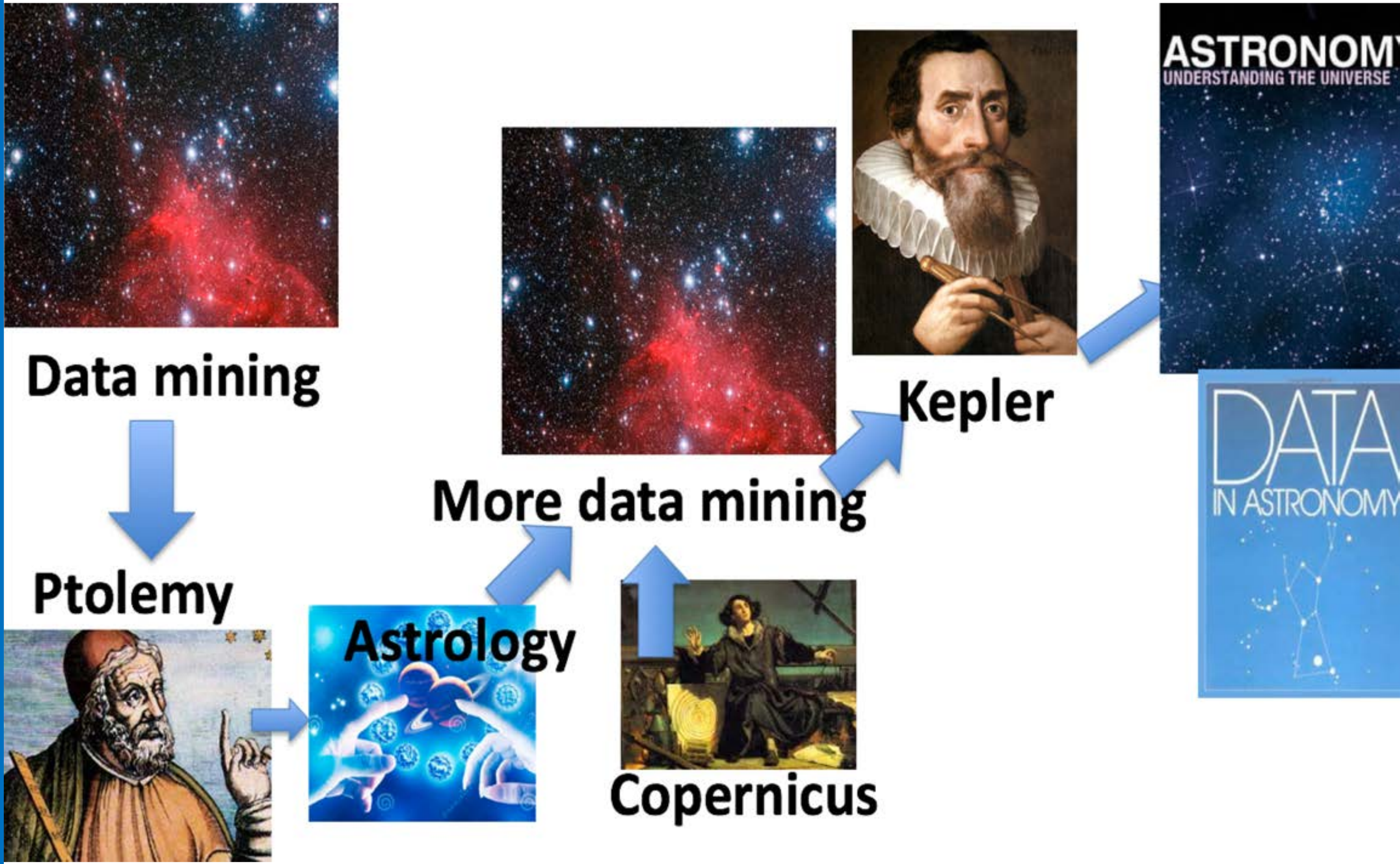
is the intellectual and practical activity encompassing the systematic study of the structure and behavior of the physical and natural world through observation and experiment."

= religion

An operational definition

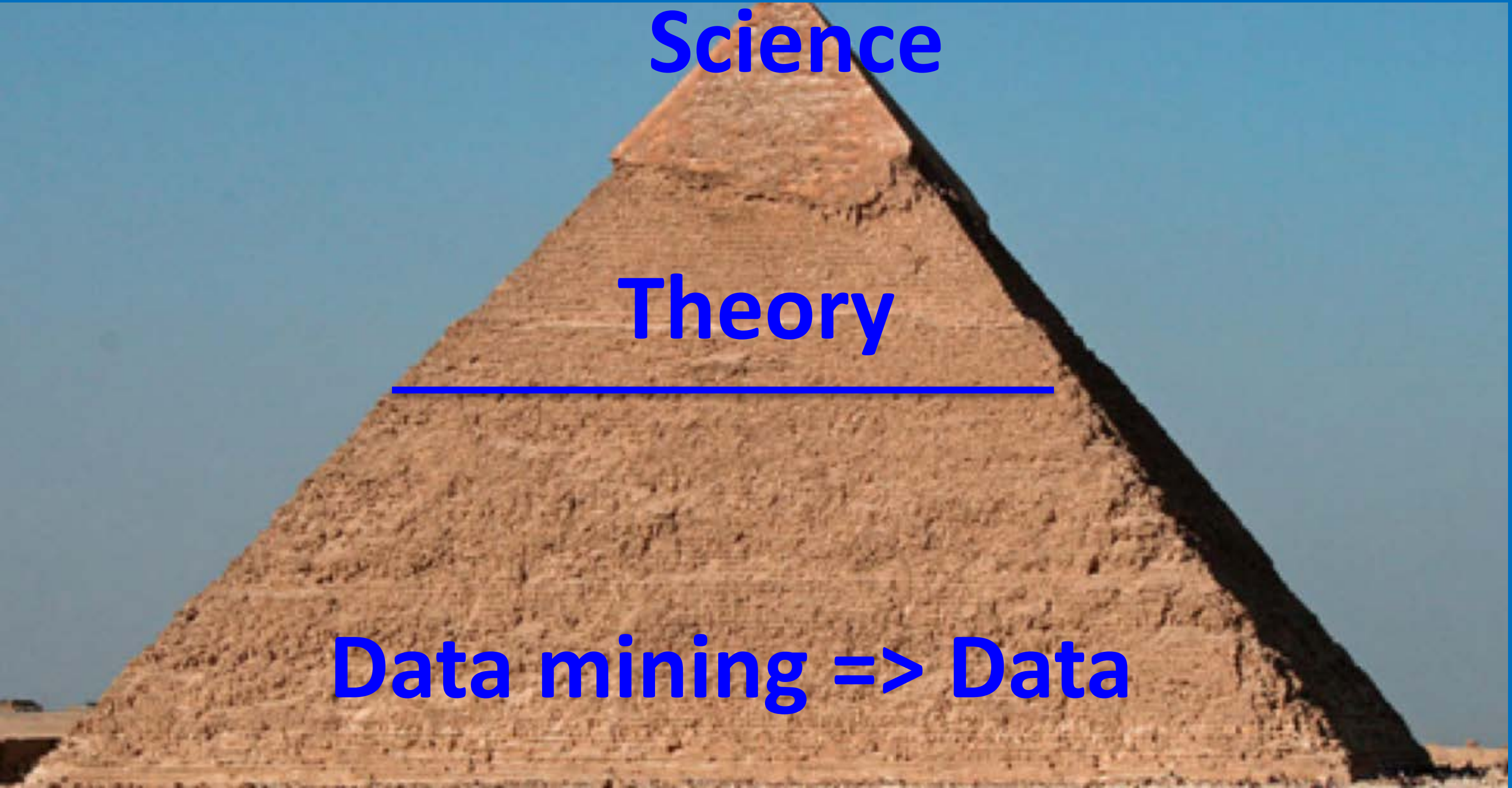
is an internally consistent body of knowledge based on the scrupulous and logical analysis of a vast amount of *data*."

For example, Astronomy dropped Astrology and became a science when Johannes Kepler finished his analysis of <u>*huge amount of data*</u> collected before him, and wrote his famous laws.



Of course, in reality there is always back and forth between theorizing and data collecting, or as we call it today – data mining, but in the end, every science is based on a solid foundation of the results of intensive data mining.

If teaching physics is not a science, can it become such? Of course. All we need is to mine a lot of reliable and comparable data.



I want to stress the *latter* word – comparable. Educational data mining is a young field. It starts producing a large amount of data.

International **Educational Data Mining** Society

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Educational Data Mining is an emerging discipline, concerned with developing methods for exploring the unique and increasingly large-scale data that come from educational settings, and using those methods to better understand students, and the settings which they learn in.

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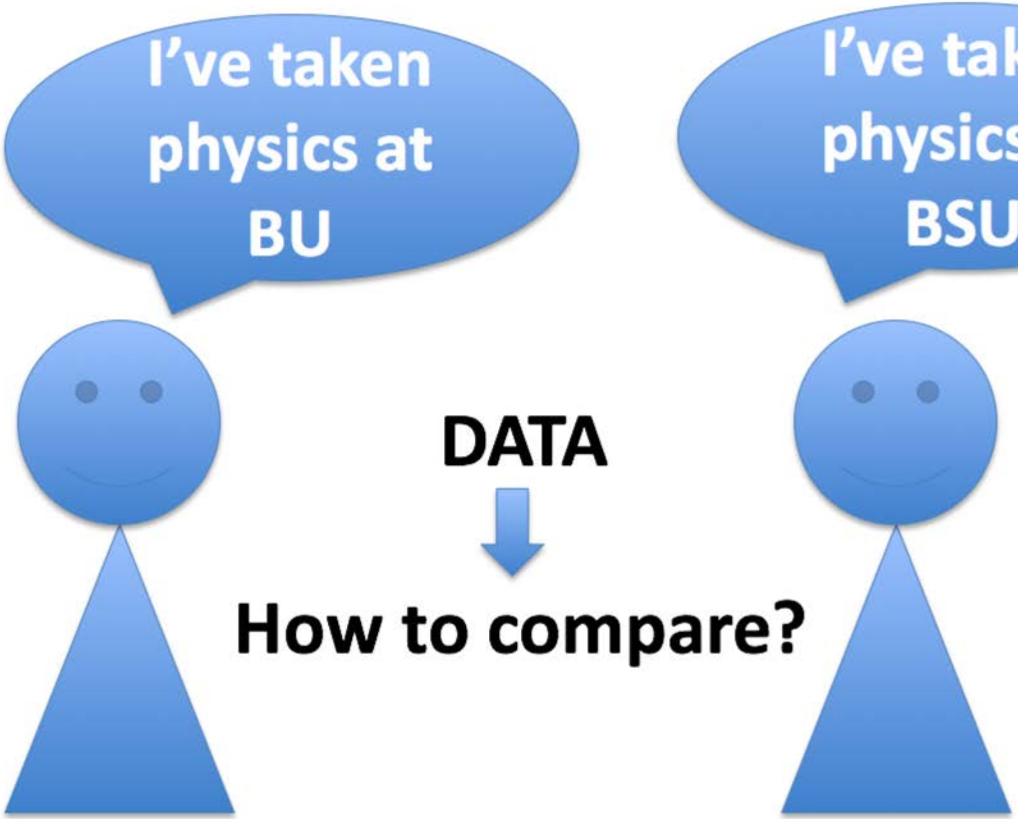
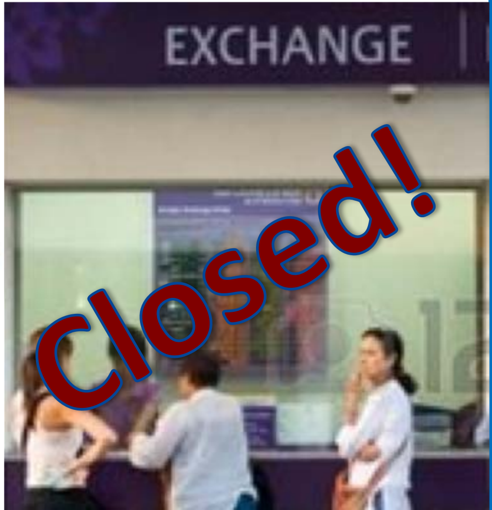
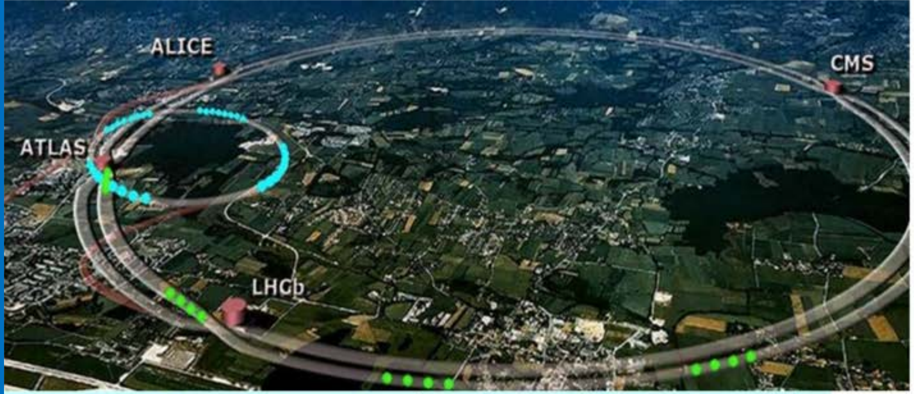


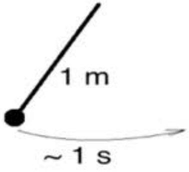
Do we have the same knowledge?

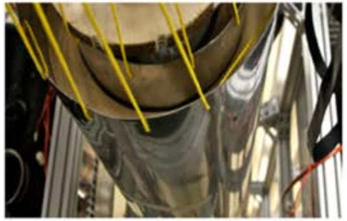


However, having a lot of data without being able to *make a comparison* is like using different currencies without establishing exchange rates.

The history of physics shows us a means for establishing the comparability we need – such means are called standards (etalons, prototypes).







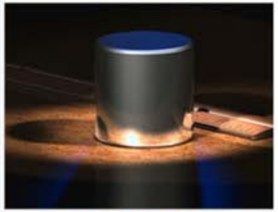
1 s *(SI unit)*

An atomic clock such as this one uses the vibrations of cesium atoms to keep time to a precision of better than a microsecond per year. The fundamental unit of time, the second, is based on such clocks. This image is looking down from the top of an atomic fountain nearly 30 feet tall! (credit: Steve Jurvetson)

Standard (metrology) **(Etalon; Prototype)**

From Wikipedia, the free encyclopedia

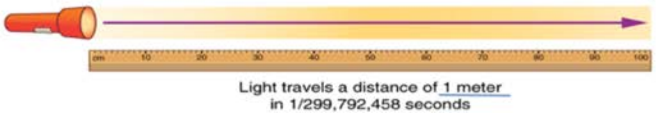
In metrology (the science of measurement), a **standard** (or **etalon**) is an object, system, or experiment that bears a defined relationship to a unit of measurement of a physical quantity.[1] Standards are the fundamental reference for a system of weights and measures, against which all other measuring devices are compared. Historical standards for length, volume, and mass were defined by many different authorities, which resulted in confusion and inaccuracy of measurements. Modern measurements are defined in relationship to internationally-standardized reference objects, which are used under carefully controlled laboratory conditions to define the units of length, mass, electrical potential, and



The International Prototype Kilogram (IPK) is an artifact standard or prototype that is defined to be exactly one kilogram mass.

1 m = one ten-millionth of the length of the meridian throug

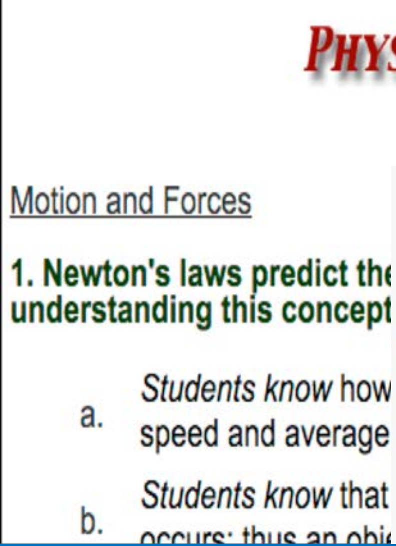
Paris from pole to the equator (1791).



The meter is defined to be the distance light travels in 1/299,792,458 of a second in a vacuum.

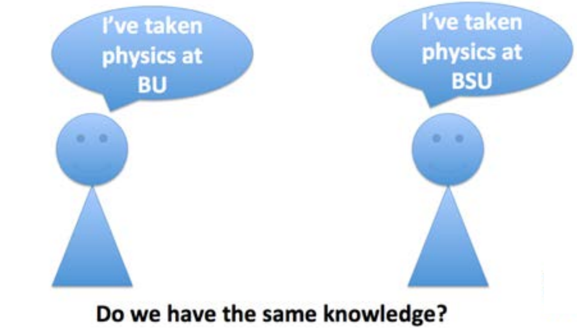
1 m *(SI unit)*

We would have never had a hadron collider built in Geneva if after an almost hundred year long journey physicists wouldn't agree on a set of common standards (etalons, prototypes).



"**Educational standards** are the learning goals for what students should know and be able to do at each grade level. Education standards are not a curriculum. **Local communities and educators choose *<u>their own</u>* curriculum, which is a detailed plan for day to day teaching.**"

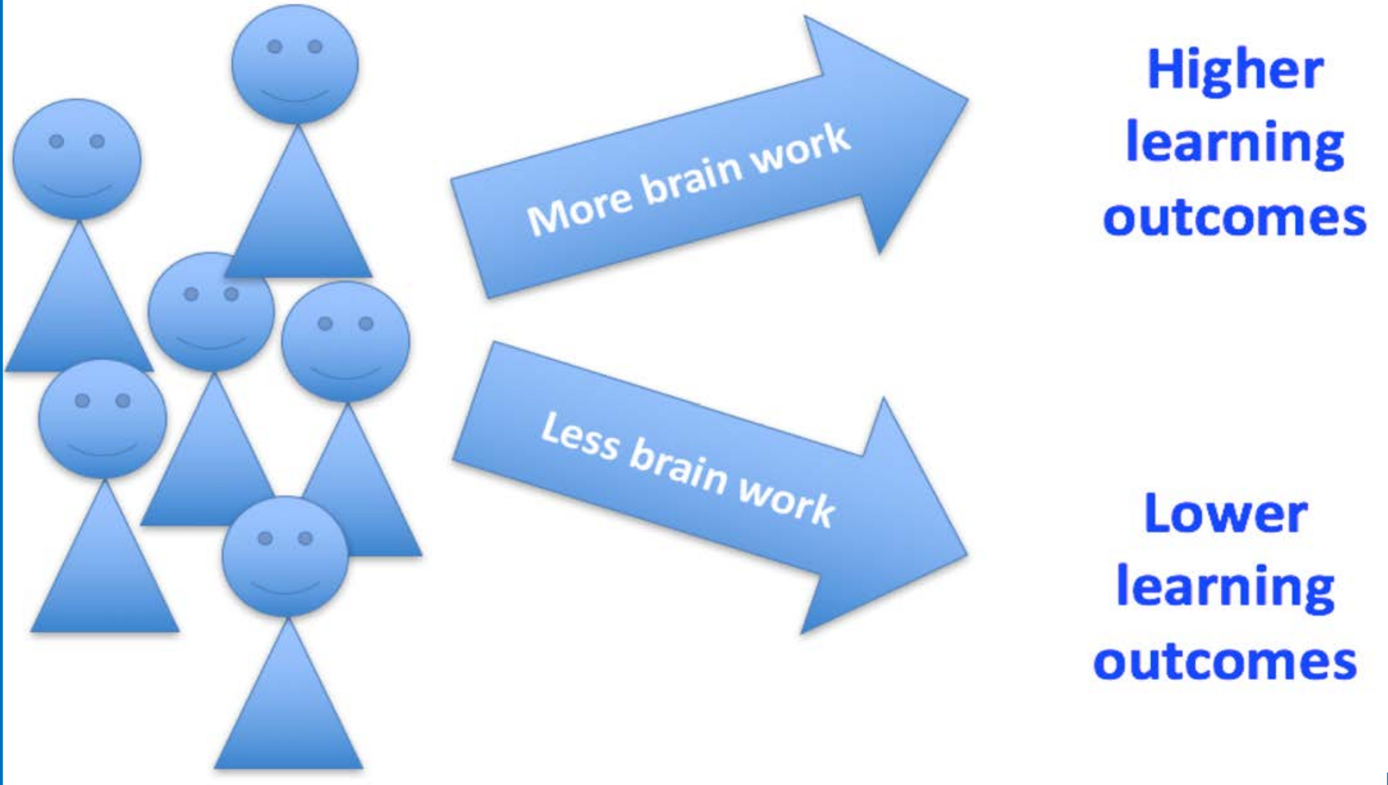
(**<u>http://www.corestandards.org/about-the-standards/frequently-asked-questions/</u>**)



There are standards in education, too. But when an educator says "a standard", he or she means something very different from what it meant in physics. In education, a standard is a textual description of "the learning goals for what students should know and be able to do at each grade level". However, people using the same educational standards still can use different measuring procedures leading to *<u>incomparable</u>* results.

Do we use the same measuring procedure?

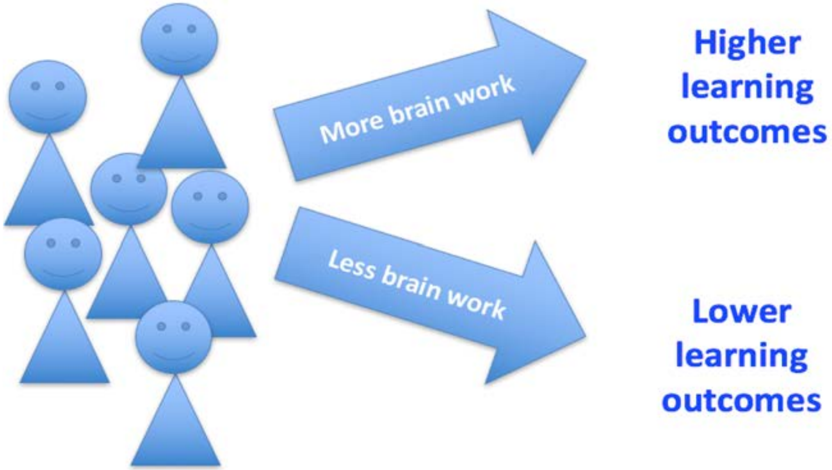
Based on those results all we can conclude so far is that: if we take two large groups of similar students, and one group of students will have a more extensive or divers learning experience

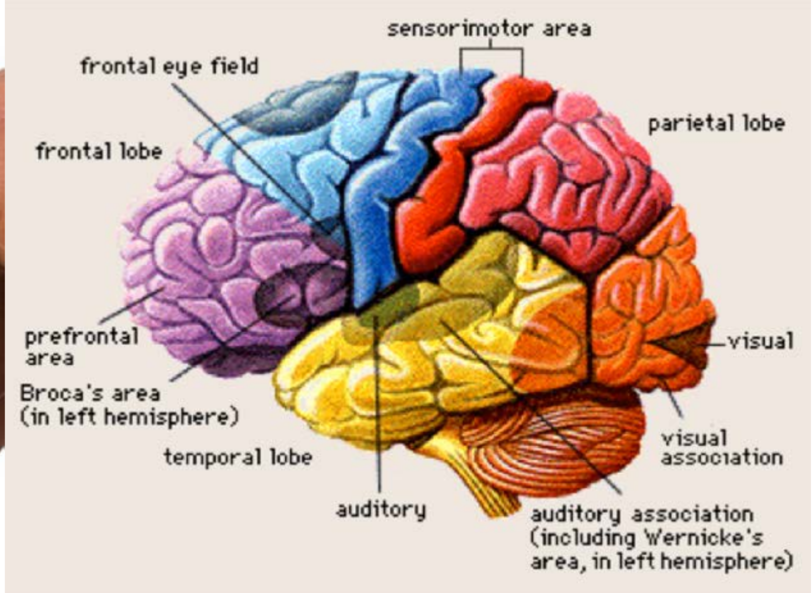


(for example, more contact hours, or more time spent on certain exercises, or training through more different exercises, etc.) students from that group, on average, will demonstrate better learning outcomes than the students in a controlled group.

This conclusion becomes almost obvious if we employ the notion that a brain is basically a muscle, or a collection of muscles, the development of which strongly correlates with the variety and intensity of exercises it goes through.

(Hail to Lumosity!)





In order to move beyond the obvious we need to adapt to *teaching* physics the same approach which had been adopted to *doing* physics. And, as in physics, we need a “standardized” standard/prototype which, like in physics, is an actual object, or a feature of an object, accompanied by a specific procedure which allows comparing similar features carried by other objects with the one of the standard.

Building a Science of Teaching Physics

Edward F. Redish

University of Maryland, College Park

Published July, 1999, in ***The American Journal of Physics.***

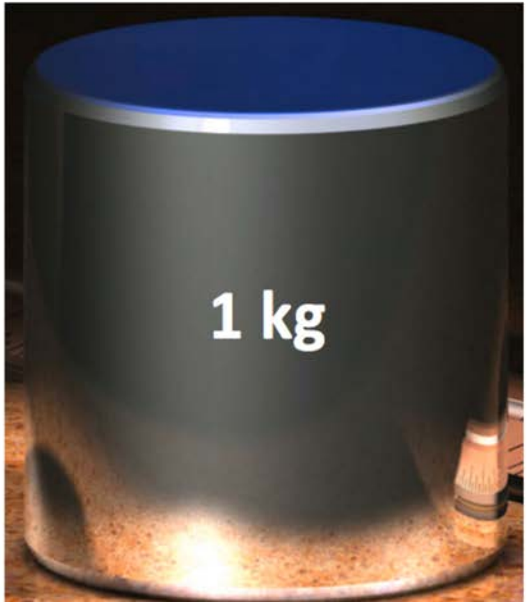
Back to overview of research

This work was supported in part by NSF grants DUE 945 5561 and DUE 965 2877.

http://www.physics.umd.edu/rgroups/ripe/perg/qm/qmcourse/NewModel/research/millikan/index.htm

For example, a standard of mass is an actual cylinder.
A verbal description (such as the one on the right) would not work as a standard, because it is impossible to compare the *mass* of an object with a *sentence*.

A standard is an object, or a feature of an object, accompanied by a specific procedure which allows comparing similar features carried by other objects with the one of the standard.



$\neq$

“A standard of mass looks like a cylinder “with diameter and height of about 39 mm, and is made of an alloy of 90 % platinum and 10 % iridium”

I believe that, following physics, "a standard" for measuring learning outcomes must satisfy the following five conditions:

(a) Every aspect of the development and the use of the standard has to be open to public and be able to be examined by *anyone*.

(b) The use of the standard must lead to gradable information on student's skills and knowledge.

(c) The use of the standard must lead to gradable information on student's skills and knowledge, AND must not depend on any specific feature of a teaching or learning process.

(d) The use of the standard must lead to gradable information on student's skills and knowledge, and must not depend on any specific features of teaching or learning processes, AND must allow to compare on a uniform basis the learning outcomes of any and all students using the standard.

(e) Any institution adopting the standard should automatically become an active member of the community utilizing the standard and can propose possible alternations to the standard to accommodate changes in the understanding of what students should know and be able to do (= "consensus building").

"Physics-like" ("true") educational standards

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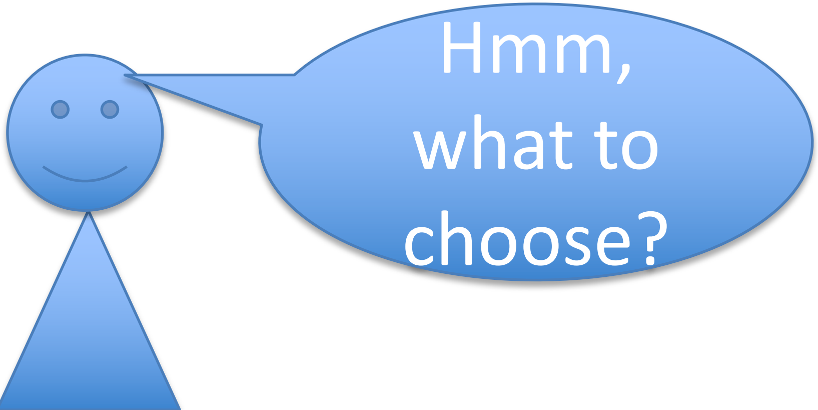
Current educational standards

"**Educational standards** are the learning goals for what students should know and be able to do at each grade level. **Education standards** are not a curriculum. Local communities and educators choose their own curriculum, which is a detailed plan for day to day **teaching**."

(http://www.corestandards.org/about-the-standards/frequently-asked-questions/)



Right now everybody in this room has a strong feeling, either "No way, in education that is simply impossible", or "Hmmm, there might be something in it worth to pursue".

“Physics-like” (“true”) educational standards

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(http://www.corestandards.org/about-the-standards/frequently-asked-questions/)

“Visionary” choice

“Follow your gut!”

“Status quo” choice

In a way, it is like choosing between “Big dreams are achievable” and “We have to aim at reasonable goals”.

An association for developing objective standards for measuring knowledge and skills in STEM subjects

Obviously, that was a joke. However, I do believe that the time has come to create a coalition of individuals and institutions who would see as an *achievable* goal developing the "universal" standard for measuring learning outcomes in physics (for starters).

So far I am the only member, but everyone is welcomed!

The methodology (a framework) for the deployment of such a standard follows “a driving exam” approach: instead of using a verbal description of what students should know and be able to do (a.c.a. “educational standards”), making them to demonstrate

what they know and be able to do using a “standardized” collection of exercises (a.c.a. “physics standards”).

This methodology is based on four fundamental principles (a.k.a. postulates, a.k.a. beliefs).

1. In physics every component of student's knowledge and every element of his/her skill set can be probed by offering to a student to solve a specific theoretical (or practical) problem (to probe rote knowledge a student can be asked a question like "what is ...").

2. For a given level of learning physics there is *always* a set of problems, which can be used to probe student's knowledge and skills.

3. For a given level of learning physics a set of problems, which can be used to probe student's knowledge and skills, has a finite number of items.

4. ALL physics problems can be classified

based (a) on the *minimal* set of the physical quantities, (b) on the *minimal* set of the physical relationships necessary for constricting the solution of a problem , and (c) on the structure of the connections between quantities (a) provided by relationships (b)

Using the fourth principle (and new terminology), we *can classify all problems* based on the structure of the internal connections between the quantities involved in constructing their solution.

All problems which can be solved by applying the exactly same sets of quantities (a) and expressions (b) and using the same sequence of steps (c) are *congruent* to each other. Problems which use the same set of quantities (a) and expressions (b) but differ by sequence (c) are *analogous* problems. Two problems for which set of physics quantities (a) differ by one quantity are *similar*.

E.G. **Problem A.** **A plain needs to reach speed of 100 m/s. Engines provide acceleration of 8.33 m/s^2. Find the time for the plain to reach the takeoff speed.**

Problem B. **For a takeoff a plain needs to reach speed of 100 m/s. It travels 600 m to reach this speed. Find acceleration of the plain during its running on the ground.** **(B is *similar* to A)**

Problem C. **A car reaches the speed of 18 m/s, moving with a constant acceleration of 6 m/s^2 (starting from rest). Find the time it takes for the car to reach the speed.** **(C is *congruent* to A)**

It is very important to note, that

<u>All</u> analogous, similar and congruent problems can be restated using a *<u>general language</u>* which does *not* depend on the actual situation described in a problem => *root problems.*

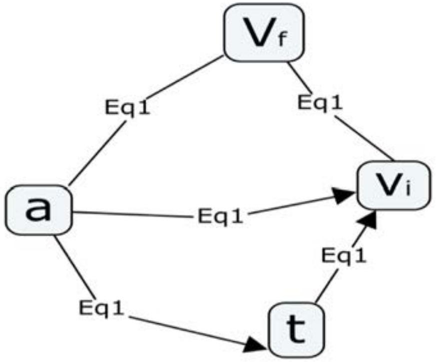
E.G. <u>Problem A.</u> For a takeoff a plain needs to reach speed of 100 m/s. The engines provide acceleration of 8.33 m/s^2. Find the time it takes for the plain to reach the speed.

<u>Problem B.</u> For a takeoff a plain needs to reach speed of 100 m/s. It travels 600 m to reach this speed. Find acceleration of the plain during its running on the ground. (B is *similar* to A)

<u>Problem C</u>. A car starts from rest and reaches the speed of 18 m/s, moving with the constant acceleration of 6 m/s^2. Find the time it takes for the car to reach the speed. (C is *congruent* to A)

<u>Root problem.</u> An object starts moving from rest keeping constant acceleration. How much time does it need to reach the given speed or to travel the given distance?

To help us to classify all root problems we can use the so-called MOCCs (a “map of operationally conected categories”).



For each root problem => visual representation

Each MOCC represents a specific example of a knowledge mapping, but must satisfy *two specific conditions*:

1. every quantity represented by a vertex of a graph must have a numerical representation, i.e. has to be measurable (capable of being measured, i.e. there has to be a procedure leading g to a numerical value of the quantity represented by a vertex).

2. every link between any to vertices must have an operational representation: i.e. for any quantity represented by a vertex, if its value is getting changed, and the values of all but one other quantities represented by other vertices connected to the changing one are being kept constant, the quantity represented by the remaining vertex linked to the changing one must change its value.

A complete set of *<u>root</u>* problems (classified based on their MOOC and difficulty) can be used for describing and probing/measuring learning outcomes of students learning physics (at least).

An association for developing objective standards for measuring knowledge and skills in STEM subjects

The first step toward the development of a *universal content standard* would be agreeing on the set of root problems (classified based on the difficulty).

A Map of Operationally Connected Categories as an instrument for classifying physics problems and a basis for developing a universal standard for measuring learning outcomes of students taking physics courses (a novel tool for measuring learning outcomes in physics).

[http://*TeachOlogy*.xyz/mocc.htm](http://TeachOlogy.xyz/mocc.htm)
[http://*TeachOlogy*.xyz](http://TeachOlogy.xyz)

By Valentin Voroshilov

The links to a more detailed descriptio n of what MOCC is and ways to use it.

Abstract

Currently there is no tool for measuring learning outcomes of students, which would be broadly accepted by teachers, schools and district officials, by parents, policymakers. Educational standards cannot provide a basis for such a tool, since for an educator "a standard" means a verbal description of skills and knowledge which students should be able to demonstrate but not an actual object, or a feature of an object, accompanied by a specific procedure which allows comparing similar features carried by other objects with the standard one (like in physics). There is however an approach to standardization of measurement of physics knowledge similar to standardization of measurements in physics. This approach is based on a specific technique used for classification physics problems. At the core of such classification is the use of graphs, such that 1. every quantity represented by a vertex/node of a graph must have a numerical representation, i.e.

Thank you!

Dr. Valentin Voroshilov

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