(1)

"A novel methodology for measuring content knowledge in physics"

(2) Hello,
I am Dr. Valentin Voroshilov.
I've been in the field of education for many years playing many different roles.
I was born and grew up in Russia. I had a pretty good career in Russia, but when I got a chance to move my family to the US, I took that chance. After starting again from the bottom I have regained most of my previous career achievements. I am pretty proud of this, considering I had no formal education in English and no professional network to support my efforts.

Dr. Valentin Voroshilov

Professional experience and areas of expertise:

Teaching:

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

Consulting:

- Individual teachers
- School administrators
- District administrators
- School and district teams of educators

on strategies and tactics for advancing teaching practices and improving learning outcomes.

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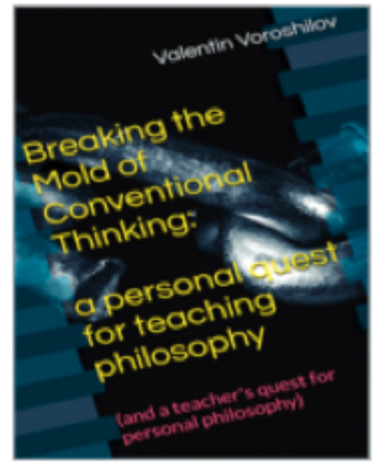

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Thinking about becoming a STEM teacher? Think

Professional Designing As One Of The Key Comp

Education reform needs a new paradigm.

A confirmation of good teaching.

How I flipped my class without even knowing it.

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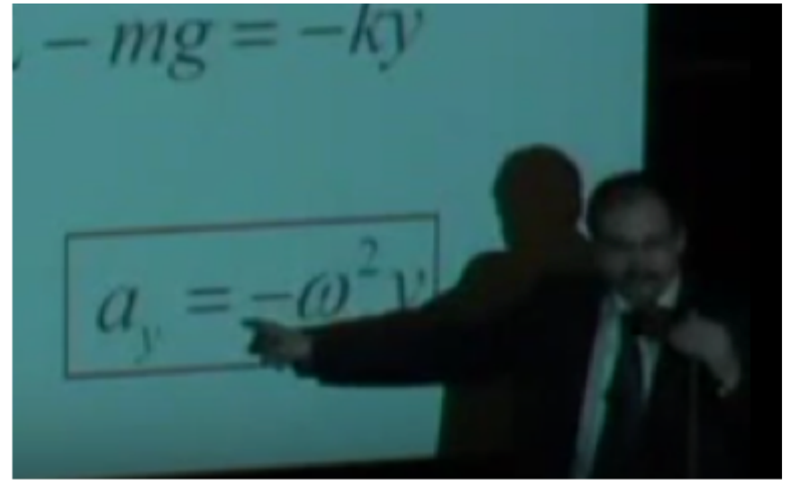
(3) **I would like to start my presentation from two statements:**
Physics is a science.
Teaching physics is not.
Of course, these statements are based on a certain definition of "science".

Physics is a science.



Teaching physics is *not*.

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(4) Personally, I do not like descriptive definitions like the one on the left (this is the top Google search result for "definition of science"). In fact, such a definition does not really allow to distinguish a science from a religion. I prefer operational 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*."

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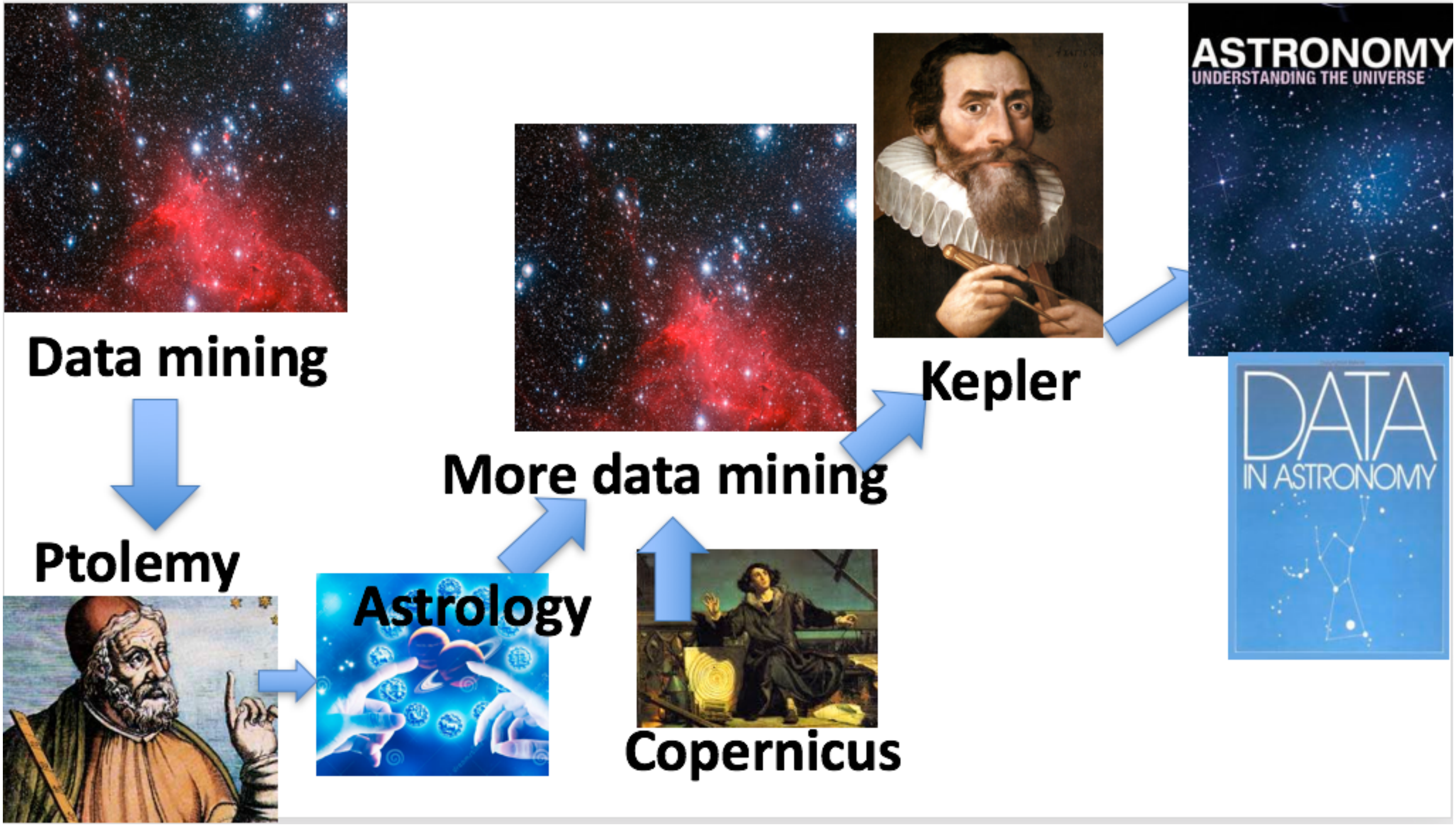
(5) **For example, Astronomy dropped Astrology and became a science when Kepler finished his analysis of huge amount of data collected before him, and wrote his famous laws. Of course, in reality there is always back and forth between theorizing and data collecting, or as we call it today – data mining, but in the end,**



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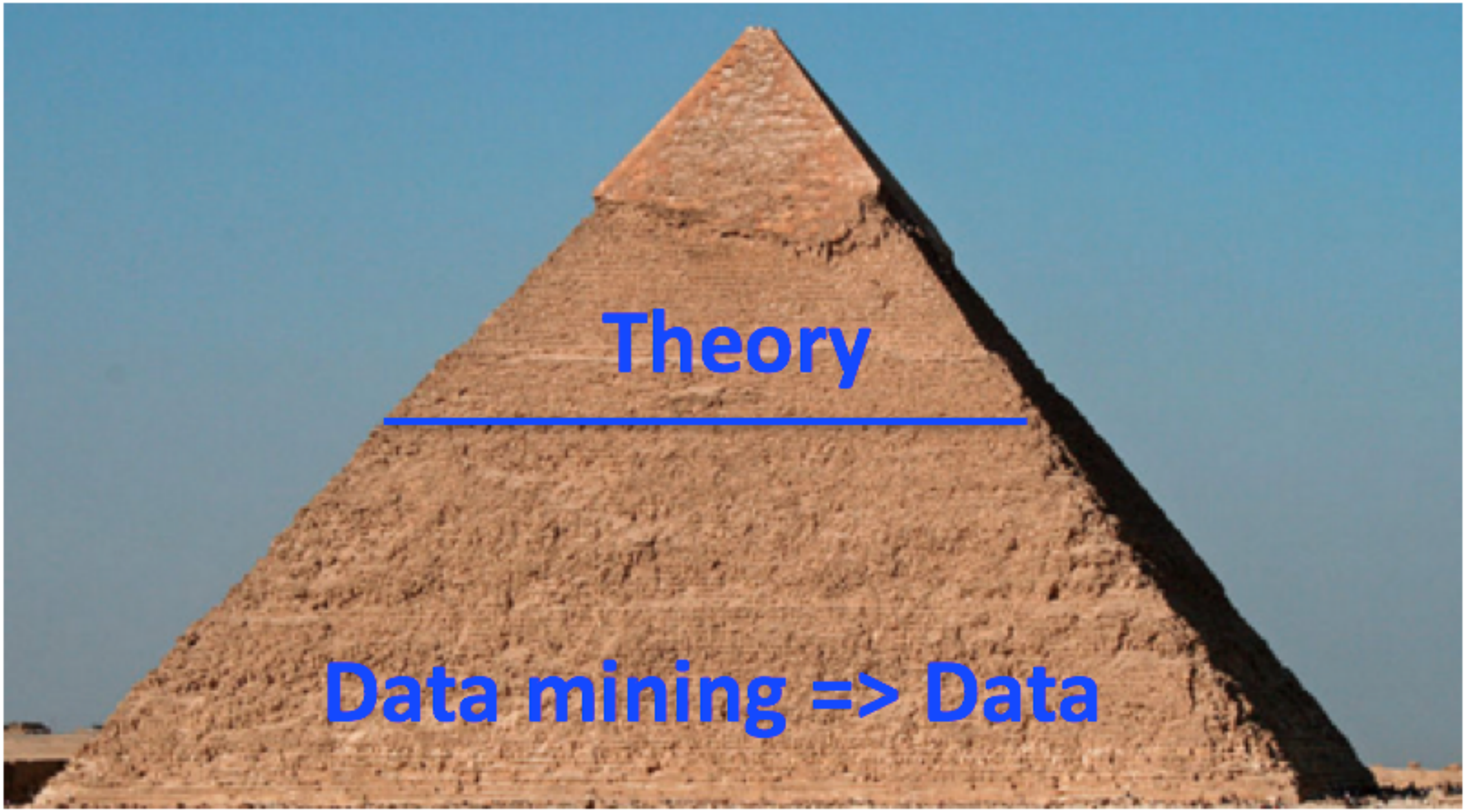
(6) every science is based on a solid foundation of the results of intensive data mining.
If teaching physics is not a science, can it become such?
Of course. All we need is to mine a lot of reliable and comparable data.

Science



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

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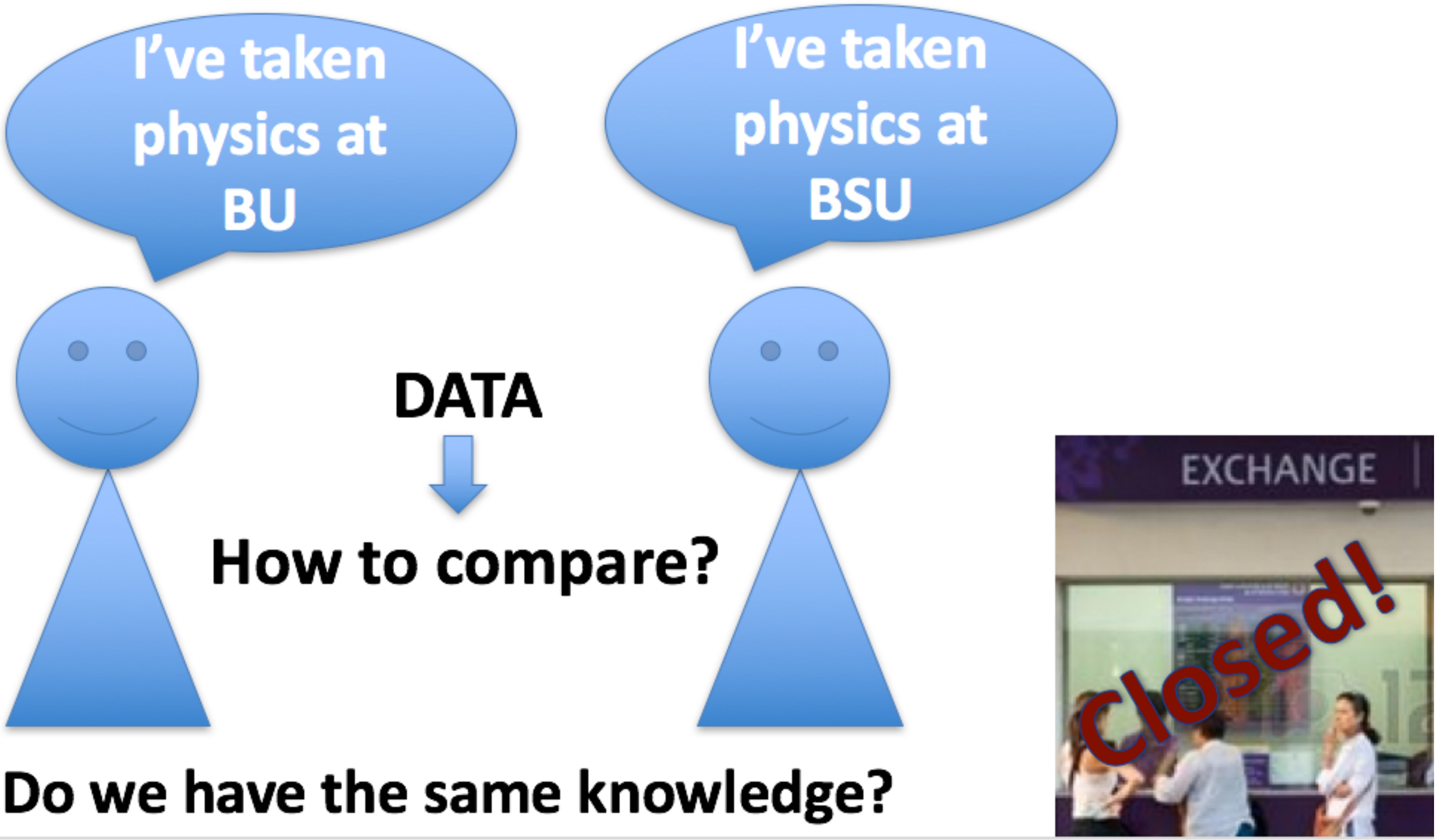
(8) **However, having a lot of data without being able to make a comparison is like using different currencies without establishing exchange rates.**



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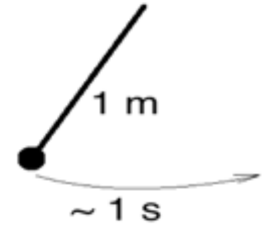
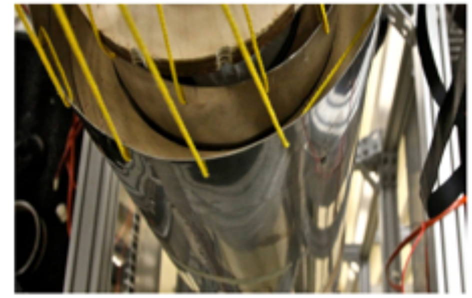
(9) The history of physics shows us a means for establishing the comparability we need – such means are called standards.
We would have never had a hadron collider built in Geneva if after an almost hundred year long journey physicists would not agree on a set of common standards.





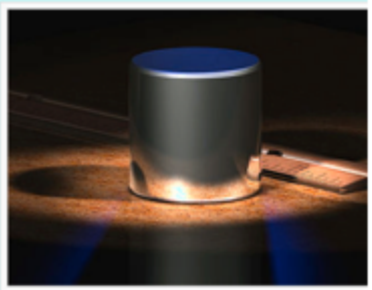
1 s ***(SI unit)***

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)**

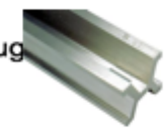
From Wikipedia, the free encyclopedia

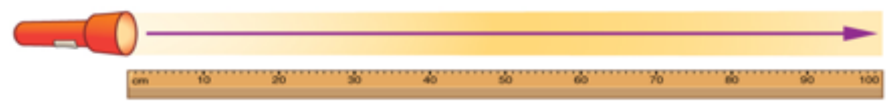
In metrology (the science of measurement), a **standard** (or **etalon**) is an object, system, or experiment that bears a defined relationship to a unit of measurement of a physical quantity.[1] Standards are the fundamental reference for a system of weights and measures, against which all other measuring 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 other physical quantities.



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).





Light travels a distance of 1 meter in 1/299,792,458 seconds

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)***

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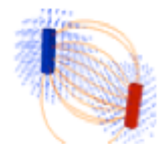
(10) There are standards in education, too. But when an educator says “a standard”, he or she means something very different from what it meant in physics. In education, a standard is a description of “the learning goals for what students should know and be able to do at each grade level”. However, people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

PHYSICS STANDARDS



Motion and Forces

1. Newton's laws predict the motion of most objects. As a basis for understanding this concept:

a. *Students know* how to solve problems that involve constant speed and average speed.

b. *Students know* that when forces are balanced, no acceleration occurs; thus an object continues to move at a constant speed or stays at rest (Newton's first law).

c. *Students know* how to apply the law *F=ma* to solve one-dimensional motion problems that involve constant forces (Newton's second law).

d. *Students know* that when one object exerts a force on a second object, the second object always exerts a force of equal magnitude and in the opposite direction. (Newton's third law).

> “**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/)

Do we have the same knowledge?

Do we use the same measuring procedure?

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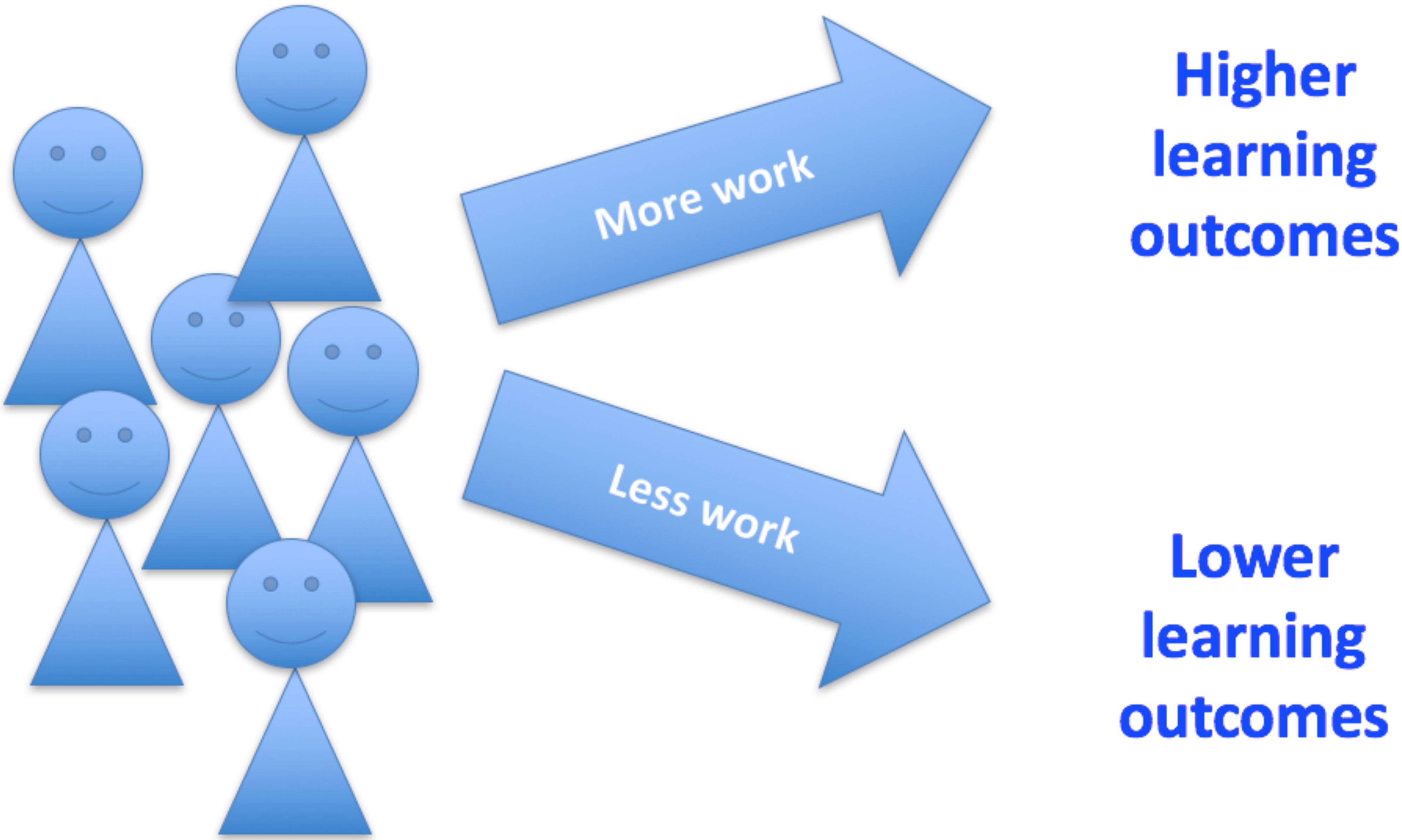
(11) Based on those results all we can conclude so far is that: if we take two large groups of similar students, and one group of students will have a more extensive or divers learning experience (for example, more contact hours, or more time spent on certain exercises, or training through more different exercises, etc.) students from that group, on average, will demonstrate better learning outcomes than the students in a controlled group.



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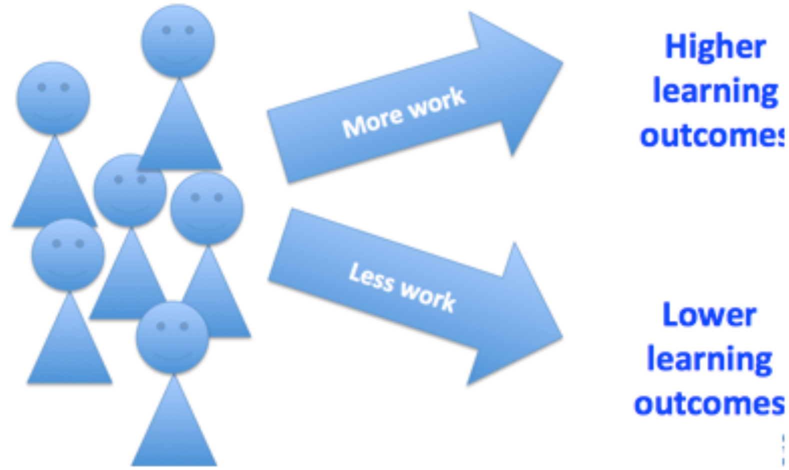
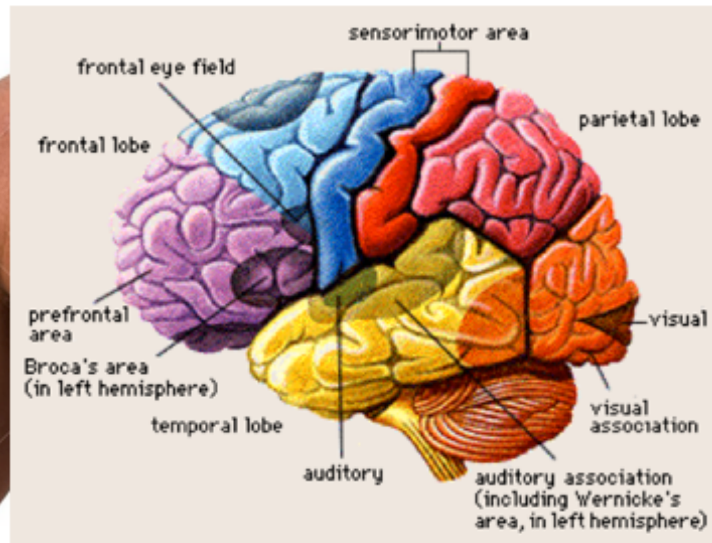
(12) This conclusion becomes almost obvious if we employ the notion that a brain is basically a muscle, or a collection of muscles, the development of which strongly correlates with the variety and intensity of exercises it goes through.





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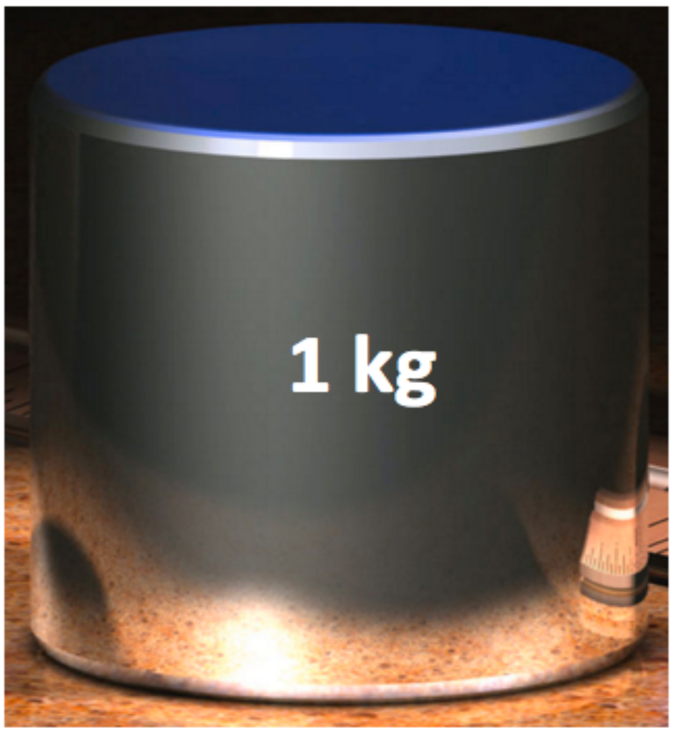
(13) In order to move beyond the obvious we need to adapt to teaching physics the same approach which had been adopted to doing physics. We need a standard which, like in physics, is an actual object, or a feature of an object, accompanied by a specific procedure which allows comparing similar features carried by other objects with the one of the standard (that is why "a standard" is also called "a prototype", or "an etalon"). For example, a standard of mass is an actual cylinder. A verbal description such as: "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" 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.



≠

"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"

<u>LINKS</u>: html: http://www.teachology.xyz/prnes.htm

(14) I believe that "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 features of teaching or learning processes.

(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.

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(15) **I want to stress that at this point this is mostly my belief. There is no solid logical proof that such standard can be developed in education. And right now, everybody in this room either has a strong feeling "no way, that is impossible", or "mmm, there might be something in it worth to pursue".**

Physics-like educational standards

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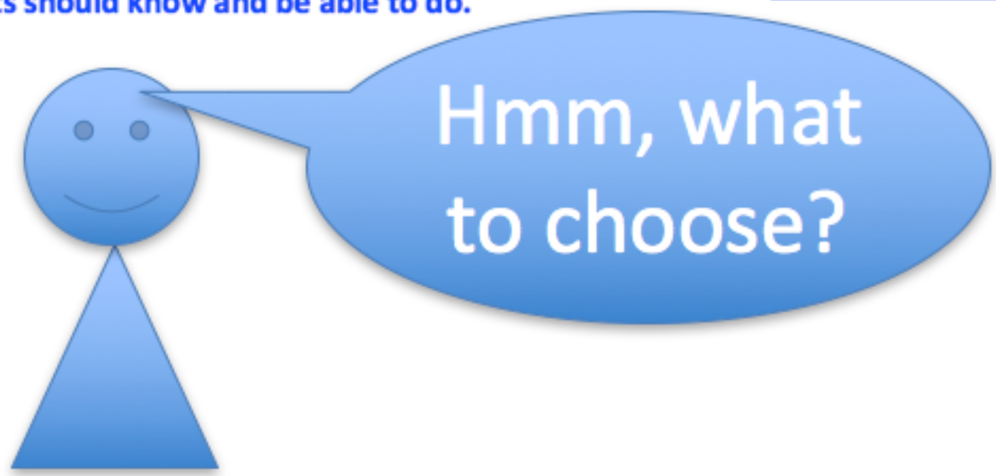
(c) The use of the standard must lead to gradable information on student's skills and knowledge, AND must not depend on any specific features of teaching or learning processes.
(d) The use of the standard must lead to gradable information on student's skills and knowledge, and must not depend on any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

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/)



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(16) In a way, it is like choosing between "big dreams are achievable" and "we have to aim at reasonable goals".

Physics-like educational standards

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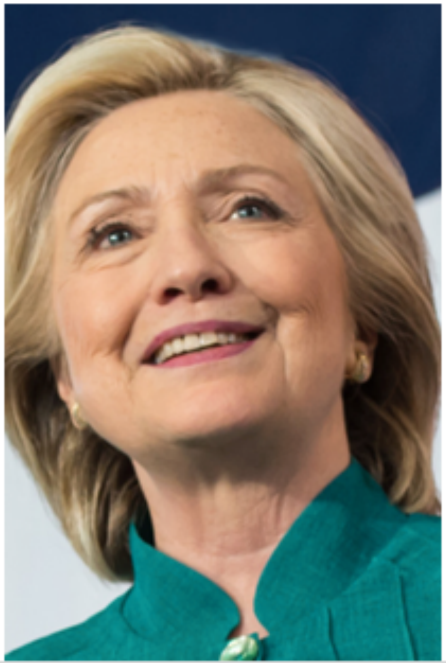
Current educational standards

"**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/)

"Visionary" choice

"Follow your gut!"

"Status quo" choice



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(17) 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 I welcome everyone!

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

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(18) Well, when I said that all I have is just a belief – I lied. I have developed a methodology which should lead to designing such a standard. The approach is following "a driving exam" approach

The new methodology is based on a "driving exam" approach: instead of using a verbal description of skills and knowledge a student has to display after taking a course (a.c.a. "educational standards"); using a collection of exercises and actions for which a student has to demonstrate the ability to perform, assuming the full level of learning (a.c.a. "physics standards").

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(19) **and is based on the four fundamental principles.**

Four fundamental principles

1. In physics every component of student's physics knowledge or a skill can be probed by offering to a student to solve a specific problem – including practical (to probe rote knowledge a student can also answer a specific question like "what is …").

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2. For a given level of learning physics there is 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.

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(21) **The last principle is the most important one.**

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, and (c) on the structure of the connections between quantities (a) provided by relationships (b) – necessary for constricting the solution of a problem.

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(22) **Using the fourth principle and the 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*.

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(23) For example, here are samples of problems which are congruent or similar to each other.

Problem A. For a takeoff 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)

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(24) It is very important, that

All similar and congruent problems can be stated using a ***general language*** which does not depend on the actual situation described in a problem => *root problems.*

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(25) For the three shown problems, the root problem sounds like the one at the bottom of the screen.

Problem A. 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.

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 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)

Root problem. 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?

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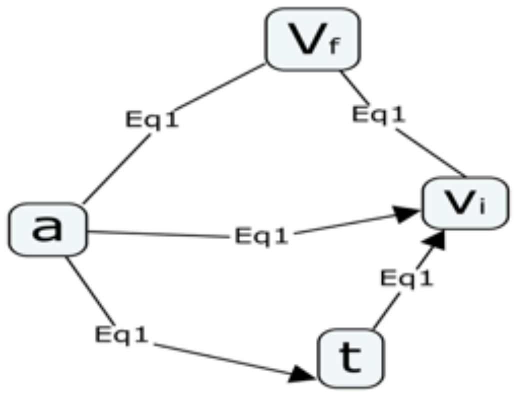
(26) **To help us to classify all root problems we can use the so-called MOCC.**



For each root problem => visual representation (MOCC)

Each MOCC represents a specific example of a knowledge mapping, but has to obey to *two strict 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.

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(27) A complete set of root problems can be used to describe desired and different levels of learning outcomes of physics students.

All similar and congruent problems can be stated using a *general language* not depending on the actual situation described in a problem

=> *root problems.*

A complete set of root problems can be used to describe desired and different levels of learning outcomes of physics students.

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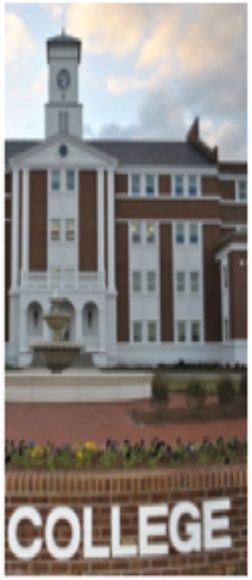
(28) The first step toward the association would be agreeing on the set of root problems and classification them based on the difficulty.



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

The first step toward the association would be agreeing on the set of root problems and classification them based on the difficulty.

LINKS: **html:** http://www.teachology.xyz/prnes.htm

(29) The link on the screen leads to a detailed description of what MOCC is and ways to use it (http://teachology.xyz/mocc.htm).

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).

By Valentin Voroshilov

http://teachology.xyz/mocc.htm

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.

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Thank you!

Dr. Valentin Voroshilov

The link to the slides with narrations:

LINKS: **html:** **http://www.teachology.xyz/prnes.htm**