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Teaching High School Physics Effectively

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The Ascending Levels of Learning and Pedagogical Maxims that could guide effective teaching of physics are presented. As an example of how these may be applied, the Dynamic Learning Program (DLP) of the Central Visayan Institute Foundation is briefly discussed. The DLP, together with 21st century technology, provides a scenario where the perennial lack of high school physics teachers in the Philippines can be bypassed.

Introduction

The breadth of topics that may be covered in teaching physics can be extremely wide. After all, physics probes the smallest things in the universe (the quarks and leptons), all the way up to the "biggest" subject one can think of—the birth, death, and fate of the universe itself. One definition for physics states that it is the study of matter and energy. Most everything in the universe is either matter or energy, and this can make physics quite interdisciplinary. No wonder, therefore, that sub-areas in physics may be referred to as Biophysics, Geophysics, Chemical Physics, Mathematical Physics, Astrophysics, Nuclear Physics, Econophysics, etc., and one also has the physics of sports, the physics of art, and so on. Because of its breadth, there is always the danger to learn physics by rote. How then do we approach the teaching of physics?

Ideally, high school physics should awaken the innate curiosity that resides in each student. It should spark the inquisitive mind and allow the learner to experience the thrill of knowing the unknown. The student should

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[1] *Parts of this paper draw heavily from other presentations of the authors, e.g., in "Best Practices in Basic Education in Asia Pacific," organized by The Coordinating Council of Private Educational Associations (COCOPEA), Century Park Hotel, Manila, 9 Nov. 2006.*

feel the joy and frustration that characterizes the process of discovery, and acquire an appreciation of the predictive power of science. To accomplish this is not an easy task. To help a physics teacher, we discuss the Levels of Learning in the next section, and discuss the following pedagogical maxims: (i) Learning by doing, (ii) Sound fundamentals, (iii) Mastery not vanity, (iv) Adaptability, and (v) Honesty. We then look at the realities in Philippine education and present a 21st century scenario for learning physics.

Ascending Levels of Learning

Being conscious of the four Levels of Learning (Figure 1) could provide useful insights in the teaching of science and math. At the base of the triangle is Visual-Kinesthetic Exploration. In trying to understand an object for the first time, one may look at its shape, color, its touch and smell, etc., almost like the way babies do. For example, one may be observing how a rough red ball falls to the ground. In the absence of the higher levels of learning, however, one may be led to think that the velocity of the falling ball has something to do with its red color.

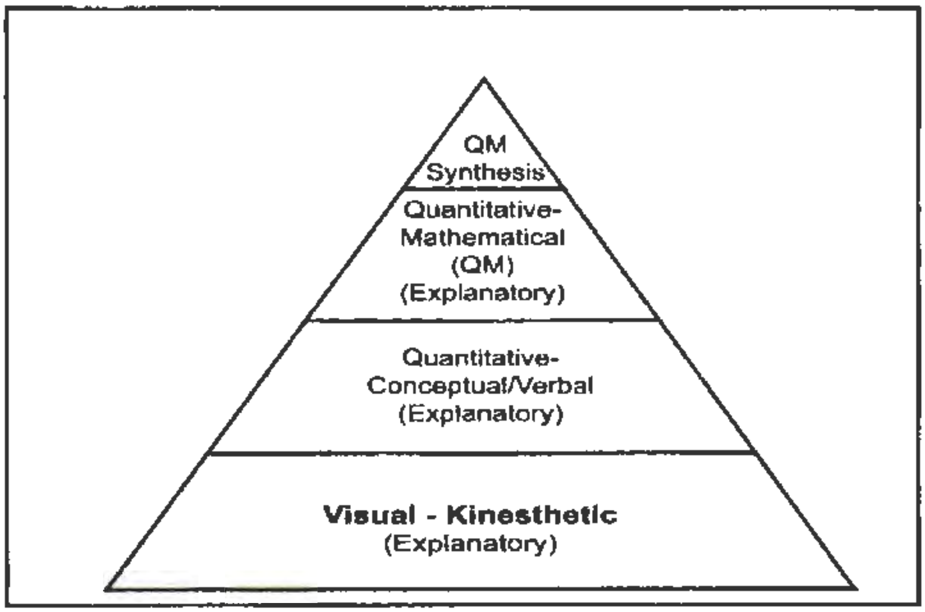

Figure 1: Levels of Learning

A step higher in the Levels of Learning is the Qualitative-Conceptual/Verbal explanation where one ventures to provide a rational understanding of a natural phenomenon. A common anecdote is often used to illustrate the inadequacy, though seemingly logical sense, of conceptual-verbal explanations. Consider a child watching a cow munching grass. The child has had the chance to play with grass, pulling it out, bunching it up, and letting it fall back to the ground. Asked why the cow does not fly even if it wanted to, the child answers, "The grass has tiny magnets inside and, therefore, once the cow eats the grass, the magnets are attracted to the earth's magnet. So the cow cannot fly." Another example is a curiosity. While introducing a lesson on gravity in a first year science class (typically 13-year old children, numbering around 45 in the class), we were surprised to see that more than half of the class initially explained gravity in terms of magnets. Somehow, their exposure to the magnet impressed them with its attractive power. In any case, the key idea here is that stopping at qualitative-conceptual explanations of observable phenomena is clearly insufficient and can be misleading. It is difficult for the layman to test the validity of premises and check the logical consistency of a chain of arguments. College students may recall the Aristotelian view that a heavier object falls much faster than a lighter one. Almost 1,900 years passed before this was disproved by Galileo Galilei through actual observation and experimentation. A popularized erroneous theory accepted for centuries is the Ptolemaic model of the universe. Galileo (again!) was involved in the dispute on the earth-centered versus sun-centered models.

Of higher order is quantitative-mathematical explanatory learning. Here, we take quantitative to mean numerical description or measurement of observables. One has to know how to measure, calculate and manipulate equations to get numbers that can be tested in the laboratory with precision. It is here where we can confirm that the velocity of a falling red ball has nothing to do with its color. This level, in fact, has enabled mankind to progress technologically by leaps and bounds. It has allowed us to explore the depths of the ocean and put men on the moon. Quantitative-mathematical learning enables us to appreciate the predictive powers of science and equips the inquisitive mind with a tool to explore the unknown. We recall, for example, what D. Halliday and R. Resnick have written :

> "…a deeper understanding of the power and beauty of this theory [quantum theory of the hydrogen atom] is not possible without a full mathematical treatment."

Galileo's thoughts on this issue are also revealing when he wrote :

> "Philosophy is written in this grand book – I mean the universe – which stands continually open to our gaze, but it cannot be understood unless one first learns to comprehend the language and to interpret the characters in which it is written. It is written in the language of mathematics, and its characters are triangles, circles, and other geometrical figures, without which it is humanly

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[2] *D. Halliday and R. Resnick, Fundamentals of Physics (Wiley & Sons, New York, 1981) p. 818.*

[3] *Galileo Galilei, in Il Saggiatore, Ed. L. Sosio, Feltrinelli, Milano (1965), p. 38. (trans. by S. Drake); underscoring ours.*

impossible to understand a single word of it; without these, one is wandering about in a dark labyrinth."

What would be the pedagogical implications of the hierarchy of learning in Figure 1? We have noticed a trend emphasizing the conceptual part of physics teaching and learning over its mathematical structure. This trend started in the 1980s and has progressed to alarming levels at present. ('Alarming levels' being taken to mean that physics learning is confined to classroom or garden demonstrations and verbal explanations of physics theories and principles. Computations and derivations from first principles, so-called formulaic manipulations, are given less attention.) Of course, this trend towards popularized physics is understandable in view of the efforts to make physics learning "fun" and more manageable. Then, too, a number of physics teachers themselves have difficulty in the rigorous mathematical aspect of physics. However, there is the risk of a backlash—weaker preparation for the rigor of college and graduate level physics and math. The rigorous approach has historically been the determining factor in the strength of a science and engineering program. And this is expected to remain so in the science-and-technology-dominated 21st century. We therefore seek a healthy balance or rather, a progressively ascending program of learning, indicated by the pyramid in Figure 1. Here, clearly the apex depends on a solid base of conceptual understanding and empirical evidence (visual-kinesthetic, which may be technologically enhanced, e.g., the use of the electron tunneling microscope in probing materials of very small dimensions).

The apex, quantitative-mathematical (QM) synthesis, is difficult to achieve but is the fountainhead for high-impact creativity and accelerated technological advancement. The quantitative-mathematical synthesis is best exemplified by the history of physical theories (see Figure 2).

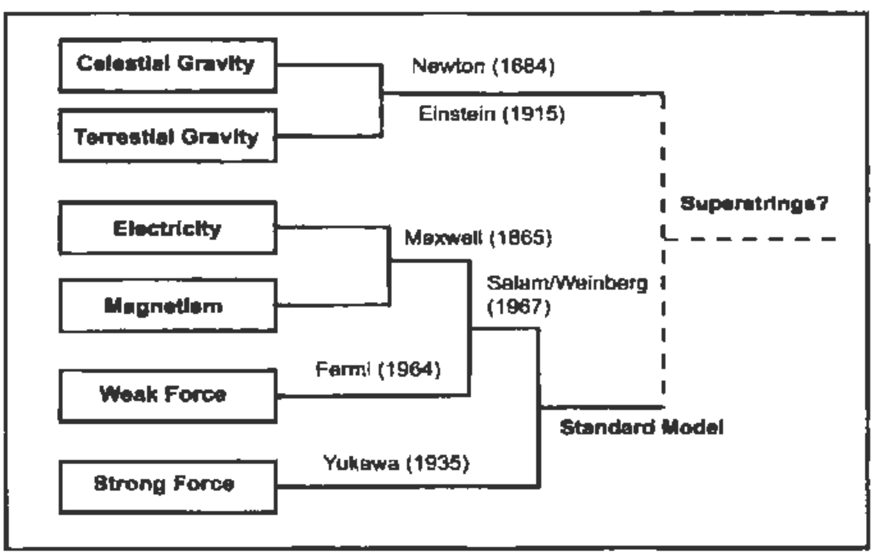

Figure 2. Historical trends in Physics

Before the 1600s, celestial gravity, which is responsible for the motion of the moon, stars, galaxies and other heavenly bodies, was believed to be governed differently from motion occurring on earth, such as a falling rock. Isaac Newton, however, proved that the trajectory and motion of the moon and a falling rock obey the same equation. Figure 2 indicates this synthesis by joining celestial and terrestrial gravity with a solid line. This view was superseded when Einstein introduced his special theory of relativity (1910) and general relativity theory (1915) with another synthesis: Space and time can be equally treated as coordinates of a four-dimensional world.

Electricity, exemplified by lightning, and magnetism exhibited by lode stones were for many centuries considered unrelated. A series of discoveries in the 1800s culminating in the mathematical formulation of James Clerk Maxwell showed that electricity and magnetism obey the same laws and equation. They also travel with the same speed which is the speed of light. Hence, today, we refer to the two as electromagnetism.

The macroscopic phenomena described by electromagnetism would later be unified with two microscopic, sub-nuclear forces: The weak force and the strong force. This unification is best explained and demonstrated by the Standard Model based on a theory first introduced by C N. Yang and R. Mills. The trend in the history of physical theories has led many physicists to believe that all the forces in nature may, perhaps, be understood in a unified form. Various attempts, e.g. Superstring Theory, have been made, but for now, we indicate this presumed unification with a dotted line in Figure 1.

To foster creativity and help develop more students up to the apex of a pyramidal hierarchy of learning (Figure 1), the Central Visayan Institute Foundation (CVIF) in Jagna, Bohol, implemented in 2002 a Dynamic Learning Program (DLP). There are pedagogical maxims, however, that guided the choice of functional strategies for the DLP. We discuss these maxims in the next section in relation with the CVIF-DLP.

Pedagogical Maxims

(i) **Learning by doing.** *For science and math, students need to think with their own minds and work with their own hands.*

This Learning by Doing maxim is most manifest in the CVIF-DLP . At the CVIF, lectures are given only 20% to 30% of the time, while the rest

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[4]*M. V. Carpio-Bernido and C. C. Bernido, in Proceedings of the 26th Annual Meeting of the National Academy of Science and Technology (NAST), July 11-12, 2004, Manila Hotel.*

of the period is left for students to accomplish the pre-designed Activities. In general, no prior lecture is given when a new topic is introduced. Once the students have acquired the habit of learning on their own they can, in fact, study and apply physics principles, solve physics problems even without any lecture.

To help teachers avoid reverting back to the traditional way of teaching, i.e., lecturing 80% of the time, the CVIF-DLP makes use of Parallel Learning Groups (Figure 3). This means that all Physics classes are held simultaneously. Since the

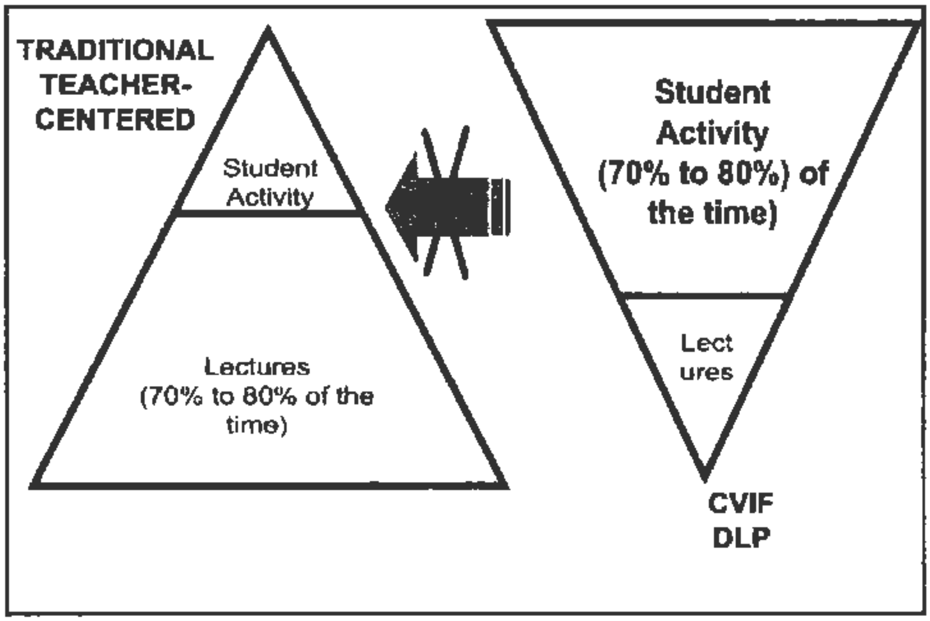


Figure 3: The parallel classes scheme provides an impenetrable barrier to prevent sliding from the learner-centered CVIF DLP back to traditional teacher-centered strategies in the course of the school year.

physics teacher cannot be in two or three places at the same time, this prevents the teacher from lecturing more than 30% of the time.

(ii) **Sound fundamentals**. *Virtuoso levels are reached only by being well-grounded in the fundamentals.*

In the teaching of science, sound fundamentals can manifest in being well-grounded in (a) the required mathematics, and (b) the scientific method.

As emphasized in our discussion of the Levels of Learning, a certain amount of mathematics is required to appreciate science. To illustrate the importance of mathematics as the language of physics, we show in Figure 4 some areas in physics and the kind of mathematics used.

Moreover, being aware of the scientific method helps eliminate errors that may proliferate at the Qualitative Conceptual/Verbal Explanation level (Figure 1). In essence, since various hypotheses are created equal in the absence of evidence, experiments have to be performed. An acceptable physical theory is one that agrees with replicable experiments.

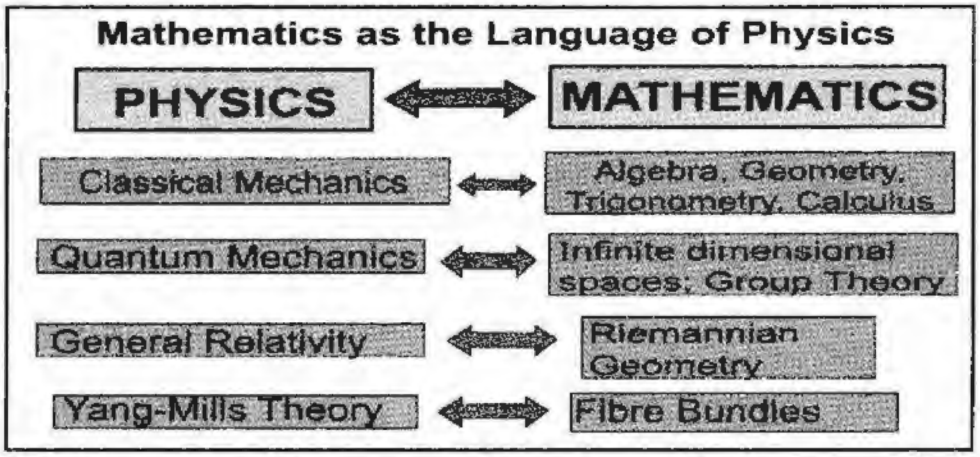
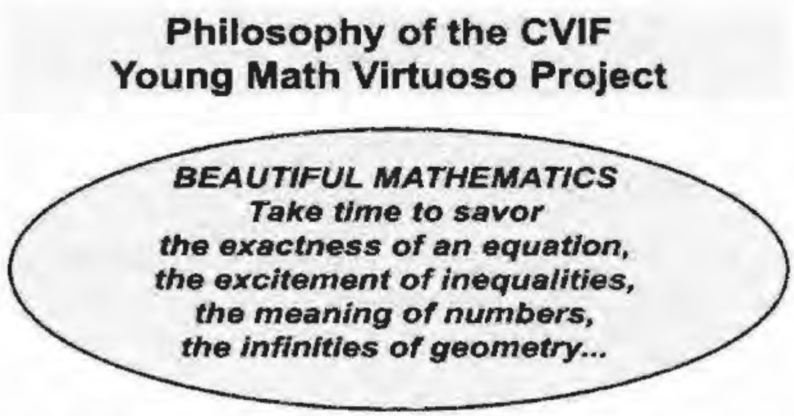


Figure 4. Mathematics as the language of physics.

(iii) Mastery not vanity. Simple problems completely and clearly solved have greater educational value than advanced problems sloppily analyzed with forced final answers.

In implementing this maxim we can cite, for example, the philosophy of the CVIF Math Virtuoso Project:



(iv) **Adaptability.** *An educational program must be adaptive because no two learning situations are ever completely alike.*

In view of the varying resources available to a school, a certain amount of adaptability should be exercised by a teacher without compromising the goal of bringing the students up the apex in the Levels of Learning (Figure 1). It may be instructive to quote a comment given by a noted Dutch physicist who was visiting the Research Center for Theoretical Physics, CVIF, for three weeks. Since the RCTP is by the sea and he had plenty of time to gaze at it he commented that, "one could actually teach the whole of physics just by looking at the sea." The deep implication of this is that effective teaching of physics need not require expensive sophisticated equipment.

Take for example a simple pendulum (Figure 5) which virtually anyone and anywhere can make. Just by tying an object with a string, one could already demonstrate the concepts of acceleration due to gravity, force diagrams, conservation of energy, simple harmonic oscillator, circular functions, wave motion, etc.

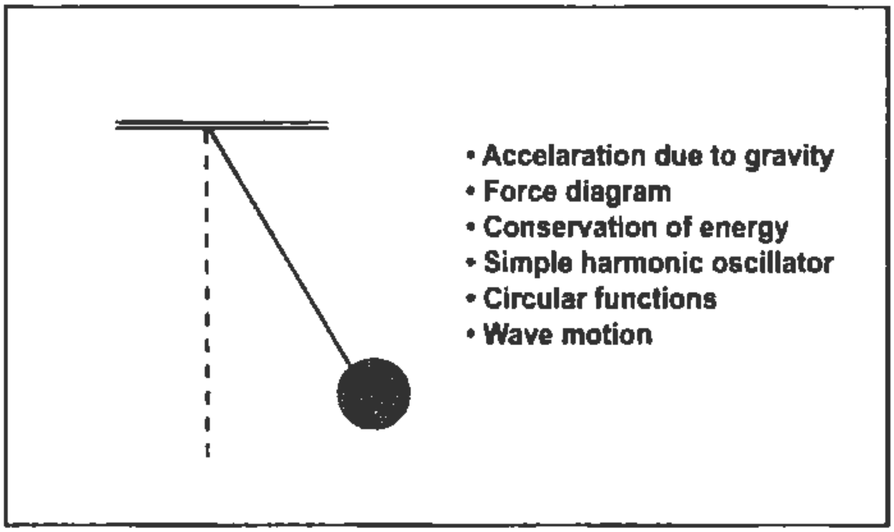


Figure 5. The pendulum.

(v) **Honesty.** *Cheating is unscientific. Fraudulent data invalidate evaluation and assessment.*

These are the five empirically based maxims which have served as a compass for the choice of strategies in the CVIF Dynamic Learning Program (DLP).

Learning as One Nation: A 21st Century Scenario

The problems which hound Philippine education range from large classes, and error-ridden textbooks to ill-equipped teachers. A Department of Science and Technology (DOST) survey, for example, showed that only 27% of physics high school teachers are qualified to teach (with a full undergraduate education/science major). The situation is further exacerbated by the massive outflow of our better teachers to foreign countries.

For schools with available physics teachers, there still exist weak links in the teaching chain. Figure 6 shows a sample teaching chain from the physics principle to be learned up to the student's understanding and application of the principle. Dashed lines show how steps may be bypassed. Clearly, any weak link in the chain can cause distortion in the teaching and learning of the principle. Any inadequacy of preparation, obscurity of presentation, or personality aberration in any part of the teaching chain can impede learning or cause physics phobia. Recognition of this fact can help us solve the problem of poor performance in physics, and science in general, of Filipino students.

To address the serious lack of qualified physics teachers in the Philippines, the "Learning as One Nation," scenario has been proposed . This involves live televised lectures by Ph.D. degree holders in the subject area. The technology needed to implement this project already exists and has been readily available to the masses. In fact, game shows have been widely exploiting them for some time now. It is feasible to bring together the experts, the school systems, as well as private and government agencies, to apply this technology to a more worthwhile endeavor: the proper education of future generations of Filipinos.

The project involves a televised live 30-minute lecture by a National Expert Teacher (NET) to be beamed to secondary schools around the Philippines at a specific time. As in many secondary schools in advanced countries, the NET should be a Ph.D. degree holder in the subject area. All the participating schools can then tune in simultaneously to allow students to watch the lectures. Students can then text, call or e-mail their questions and receive feedback from the expert teacher in real time. Teachers from the individual schools will serve as Facilitators during the forum. This project allows a short and medium term solution to the worsening problem of poor math and science preparation of students due to under qualified teachers at the Secondary level. There are excellent professors in universities in math and the sciences. What is needed is to bring their expertise to the secondary schools in the most efficient way possible, and that is through mass media and instant messaging via text or internet, or through phone calls.

Since lectures by the NET are only once a week, the rest of the time will be spent by students doing the Activities designed by the Expert Teacher. This emphasizes the fact that mastery in the subject area, especially science and math, can only be acquired following the "learning by doing" principle. The "Learning as One Nation" project is, in fact, an offshoot of the positive experiences derived from the CVIF-DLP. In particular, students can acquire mastery even if lectures on a subject are limited to only 20% to 30% of the

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[5] *M. V. Carpio-Bernido and C. C. Bernido, "Learning as One Nation," Philippine Daily Inquirer, p. A16, Nov. 20, 2005.*

time complemented with pre-designed Activities.

In view of the huge cost involved in a live lecture, a scaled down version is now in preparation with the pilot phase to be implemented in school year 2008-2009. The "Learning Physics as One Nation: the Physics Essentials," funded by the Fund for Assistance to Private Education (FAPE) will utilize videotaped 15-minute lectures and demonstrations of national experts in VCD format. Learning Activities to be accomplished by students would be in an accompanying Physics Essentials Portfolio.

With additional support from the private sector and the government, the impact of this project may still be expanded.

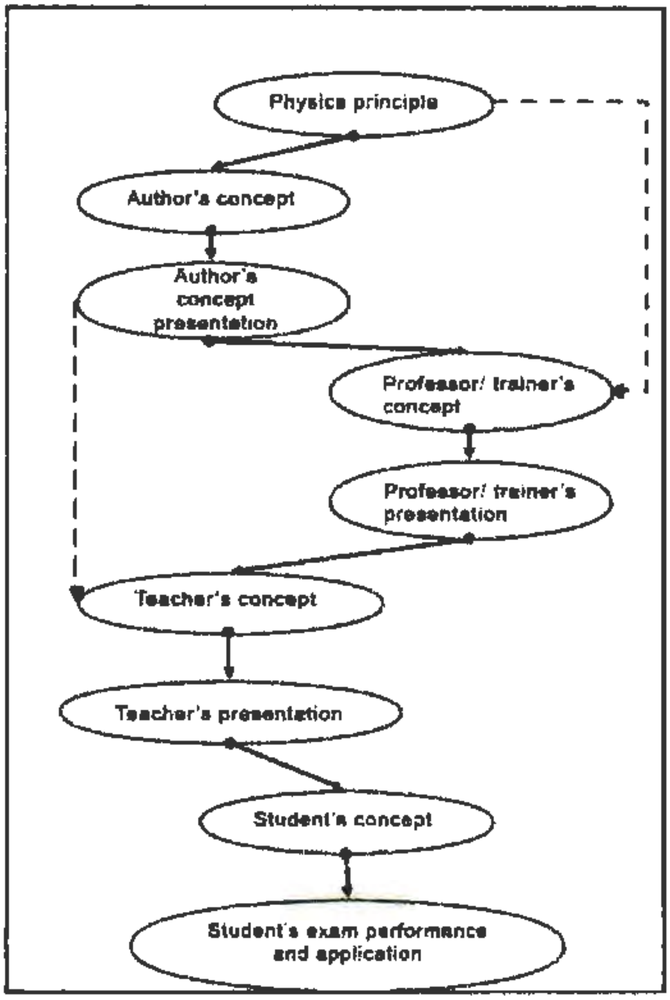

Figure 6. Weak links in the teaching chain.

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