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THE TRAINING OF A PHYSICIST: FROM CONCEPT BUILDING TO PROBLEM-SOLVING SKILLS*

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ABSTRACT

Physics teaching in Pakistan does not produce physicists capable of bringing out new concepts. Neither, they are trained in problem-solving skills. This paper focuses on the factors contributing to this state of affairs. Further, it proposes strategies to reverse this situation. Recommendations of the conference are presented at the end.

Keywords: Pedagogical techniques, concept building

INTRODUCTION

Physics study occupies a most important part of today's education. But what is really physics and what is not physics. Can physics answer all of the questions faced by the humankind? Certainly, physics has its limitations. It can only deal with what can be observed or felt. It cannot make value judgments. There are also limitations of time to find the answer as well as lack of absolute certainty in the answers. Even well-accepted theories have a dead end somewhere. Consider big bang theory of creation of the universe. What was there before the big bang? How was there such a huge energy concentrated in a small volume? These questions and others shall continue to haunt minds of the inquiring and seekers of the truth. To quote Freeman Dyson (1979) of the Institute of Advanced Study, Princeton, USA: "no matter how far we go into the future, there will always be new things happening, new information coming in, new worlds to explore, a constantly expanding domain of life, consciousness and memory".

Physics teaching in Pakistan is facing a dilemma these days (Siddiqui & Kamal, 1987). Students are not motivated (Kamal, 1998). Most of the time they lack basic concepts of the scientific method (Kamal, 1997 *a*; *b*). There is a need to develop undergraduate and graduate physics curricula (Kamal, 1986; Kamal & Siddiqui, 1989), which inculcate creative thinking and critical analysis in students (Kamal & Siddiqui, 1986). Mathematical foundations, needed to develop the concepts and the ideas of physics, must be a part of this curriculum (Siddiqui & Kamal, 1986).

The training of a physicist should result in creating concepts in trainee's mind about energy, conservation laws, equilibrium, steady state and non-equilibrium. It should introduce the incumbent to paradigm shifts in physics (Kamal, Siddiqui & Naseeruddin, 2000). A physicist equipped with crystal-clear concepts should be able to solve problems, in the classroom, in the laboratory and, finally, practical problems related to industry.

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STAGES OF CONCEPT BUILDING

A concept is built in four stages - acquisition, formation, development and application. All these stages must be incorporated in the depth and the breadth of curricula. The curriculum, itself, should not be static. It must be constantly evolving on the basis of inputs from the students, the peers, the parents and the experts (who should critically review the teaching sessions from videotapes, *etc.*) and must conform to needs of the society it is designed for http://ngds-ku.org/subprojects.htm#Pre_University. No matter how good the curriculum is, it would not serve its purpose unless the teachers are motivated

http://ngds-ku.org/subprojects.htm#NGDS_Workshops

and their own concepts are clear and firm (Summers, 1995; Kamal, Siddiqui & Naseeruddin, 2003). Before teaching a new concept students' perception of the topic must be assessed (Toh, Boo & Woon, 1999). Any wrong or distorted concept already present must be identified. With the right concepts mapped properly the students shall be able to relate and to borrow concepts and techniques learnt in various disciplines and sub-disciplines for the solution of problem(s) at hand (Kinchin, Hay & Adams, 2000; Lawless, Smee & O'Shea, 1998). Given below are examples, which show similarities in different disciplines:

a) Electric and gravitational potential**:** similarity in mathematical expression
b) Fast freeze in structural biology and fertilizer production**:** similarity of process

CONCEPT BUILDING THROUGH ACTIVITIES

Here is an example of how the author introduced a few concepts in physics and mathematics through activities. A seven-year old child, student of class two, was watching television, while sitting close to it. She had not learnt measurement techniques and multiplication. The goal was to measure a distance five times the diagonal length of the television screen, to be marked as proper watching distance. The child did not know how to measure a length. First, she had to be taught how to take the length of an object, say, a pencil. To find the length she aligned the pencil with a ruler, placed, somewhere, in the middle of ruler. She took one reading at the tip of pencil and another at the end. She, then, subtracted the later from the former. This was a practical application of subtraction. She was suggested that a length should not change if readings are taken using some other part of ruler. She verified the idea and, hence, learnt the concept of reproducibility. Next, she applied the measurement technique just learnt to measure the diagonal length of the television screen. Since she had no concept of multiplication she added the figure five times to obtain safe distance. Finally, she measured this distance from the television screen to find a proper seating place. Such activities reinforced the concept of safe-viewing distance at the same time teaching many other concepts and skills. The concepts learnt were:

a) Meter as unit of length
b) Measurement techniques
c) Reproducibility of measurements
d) Mathematical concept of multiplication as repeated addition
e) Practical application of subtraction (to compute length)
f) Health and safety concept of safe distance to watch television

APPLICATION OF CONCEPTS: PROBLEM SOLVING

There has been a saying: I have learnt all the theory, but I cannot solve any problems. In other words, I have crammed all the equations and the formulae, without understanding their significance, their applicability and their limitations. A hands-on approach is required to *Experience Physics*. If one learns physics concepts properly, one should be able to solve unseen problems (unseen problem is the one not covered in tutorial or in homework). This is the major difference in teaching strategies of Pakistani institutions versus US institutions. The former focus on definitions and derivations, whereas the later emphasize on concept building and problem-solving skills.

PROBLEM SOLVING IN THE CLASSROOM

Students face difficulty in setting-up a word problem. Solution becomes easier if the word problem is dissected as follows:

Data:	Whatever is "given" in the problem
Objective:	Whatever is "to find" (to draw, to prove) in the problem
Solvability:	Whether the problem is over determined, critically determined or under determined
Strategy to solve the problem:	The physical law or the mathematical equation applied to solve + the assumptions/ the limitations of the model used [mention of alternate methods available, most efficient method to reach a solution]
Setting-up of the problem	Coördinate axes, diagrams, conversions in SI [include a table of conversion factors used, symbols/terms used] (Bukhari & Kamal, 1987)
Solution of the problem:	Solution using mathematics, physics or logic [solution to be in two columns, the left-hand column containing steps of the solution and the right-hand column their justifications]
Result(s):	Should be quoted to proper significant figures, solely in the language of data and objective, without referring anything introduced in setting up of problem

PROBLEM SOLVING IN THE LABORATORY

Laboratory problem solving is a very systematic activity. Following are the steps needed to solve a problem using the scientific method (Kamal, 2003*a*):

a) Observing a natural phenomenon.
b) Developing a question about cause and effect.
c) Formulating a tentative answer to the question (the hypothesis) through inductive generalization from the observations.
d) Testing the hypothesis by taking further observations/conducting an experiment.

PROBLEM SOLVING IN THE INDUSTRY

Industrial problem solving is a focused activity. One has to develop a marketable product/service or improve properties of an existing product. For this purpose one needs to have a well-defined statement of the problem, formulated after comprehensive literature survey. Before embarking on a full-scale project one must conduct feasibility studies, and run pilot projects. For this purpose one may need to design *Efficient Experiments*. Efficient experiments identify scope of the project, the variables of interest and their interaction at a very early stage. *Poor Experiments* can result in wrong decisions. *Inefficient Experiments* result in excessive cost or time delay in reaching a decision. The main reasons are lack of training in the strategy of experimenting, incorrect decisions based on insufficient data, bad engineering decisions by setting vague objectives for projects, inappropriate statistics courses taught in the colleges and in the universities (Kamal, 2003*a*). One may, then, embark on developing prototype, phenomenological, or fundamental models as per requirements of the end user. Simulations, test runs and field trials may be needed to improve the model, so as to make the product/the service commercially viable (Kamal, 2003*b*).

The first stage of industrial problem solving is developing a project proposal, outlining the funding, the resources and the time constraints involved in accomplishing the task. The outcome could be a product or a service. A suitable format may be found on my homepage.

SUMMARY AND RECOMMENDATIONS

The conference addressed many vital issues. Lectures and workshops dealt with concept mapping, problems faced by the physics teachers and long-term policies regarding physics education. The following recommendations were put forward by the conference:

a) Physics should not be war-oriented, but peace oriented.
b) Quality education must be linked with proper health care.
c) Conceptual development and problem-solving skills must be emphasized at all levels starting from the primary school.
d) Students should be trained to write proposals to solve problems faced by the local industry (textbook problems should prepare them to tackle industrial problems); internships to be given based on the quality of proposals prepared.
e) Curricula should be developed and be updated regularly; curriculum development should be a “process”, not an “event”.
f) IT resources should be utilized to Physics Teaching at all levels.
g) Real-life examples, thought experiments and models (to be constructed by students, themselves) should be used to stimulate thinking and questioning process.
h) Students should be trained in the art of questioning.

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