PROCEEDINGS

of

National Conference on

EMERGING TRENDS IN PHYSICAL SCIENCES

(NCETPS-2015)

January 23-24, 2015

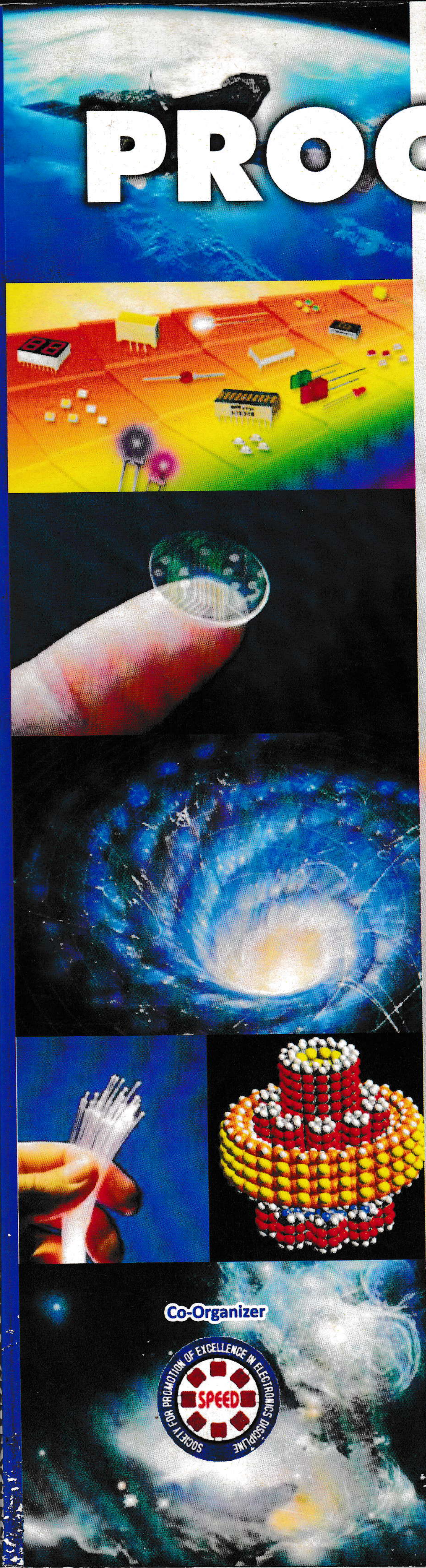
ISBN:978-93-5212-614-9

EDITORS

Prin. (Dr.) A.S.Kulkarni

Dr. T.N.Ghorude

Mrs. M.P.Patil



Organized by

Department of Physics,

GES's N.B.Mehta (Valwada) Science College,

BORDI (Maharashtra)-401701

ISBN- 978:93- 5212-614-9

The Science Learning through Modeling and Simulations

Pravin Joshi[1], Prakash Landge[2] and Rajendra Vadnere[3]

1. Department of Physics, H.P.T. Arts and R.Y.K. Science College, Nasik, Maharashtra, India, Pin- 422005. Mob: 9423968110, E-mail: skycom.nsk@gmail.com

2. Department of Physics, R.N.C. Arts, J.D.B. Commerce and N.S.C. Science College, Nasik-Road, Nasik, Maharashtra, India, Pin- 422101. Mob:9420694840, E-mail: pgl_nsk@rediffmail.com

3. School of Continuing Education, Y.C.M. Open University, Nasik, Maharashtra, India, Pin- 422222. Mob: 9422292640, E-mail: dir_cnt@ycmou.digitaluniversity.ac

Abstract

It is well-known fact that the average retention rate of active or participatory teaching/ learning methods is always greater than passive or traditional classroom-teaching/learning methods. But, compared to traditional methods, active teaching/learning methods require setup of huge laboratories and well trained demonstrators. However, for mass-learning process, we still have to depend on classroom teaching, though; the average retention rate is very less.

The proper blending of the traditional method of teaching with the active or participatory teaching/learning method would perhaps be the practical approach to achieve the goal of acquiring the desired learning outcomes in terms of retention rate. Thus, judicious mix of traditional as well as active teaching/learning methods may help the teachers increase average retention factor of the students undergoing training. The proposed work in this direction is discussed here. To test effectiveness of judicious mix of teaching/learning methods, a novel technique developed at University of Maryland Physics Education Research Group is used. This technique explores students' model states using the tool of eigenvalue equations.

Keywords: Judicious mix of teaching/learning methods, Students' model state.

1. Introduction

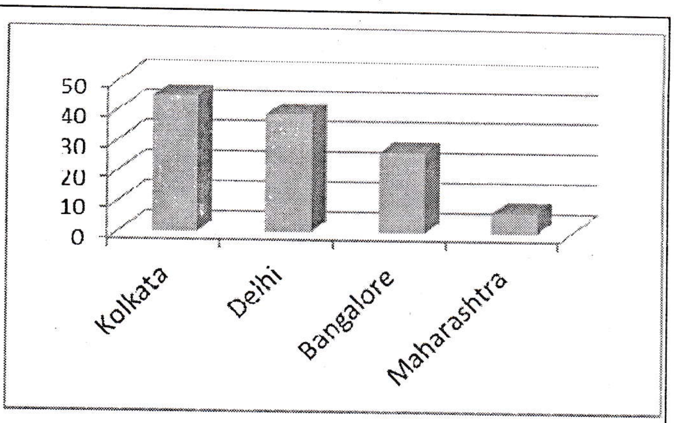
Science Education in India has been subject of several studies and analyses over the years. Various problems in the system have been pointed out and remedies have been suggested but they have not made any dent in the problem.

Senior Scientist and Bharat Ratna recipient CNR Rao told the Times of India in an interview (Aug 5, 2014), that *"Science taught in schools and colleges in India is 'completely outdated', 'most boring' and is no longer the one practiced in advanced laboratories"*. He further said that *"Science we teach in schools and colleges is no longer the science we actually do in advance laboratories. ... The chemistry which is taught in high schools...who wants to learn that chemistry?"* He also said that *"education and science was not given due importance in the country"*.

It is a fact that students do pass the examinations conducted by the universities with flying colors, but they do miserably when facing the examinations like State Eligibility Test (SET) or the similar competitive examinations. A simple statistical analysis of the entrance test (ET) to the admission to M. Sc. Physics; conducted by Savitribai Phule Pune University (ET Result 2014) across the country bear testimony to this.

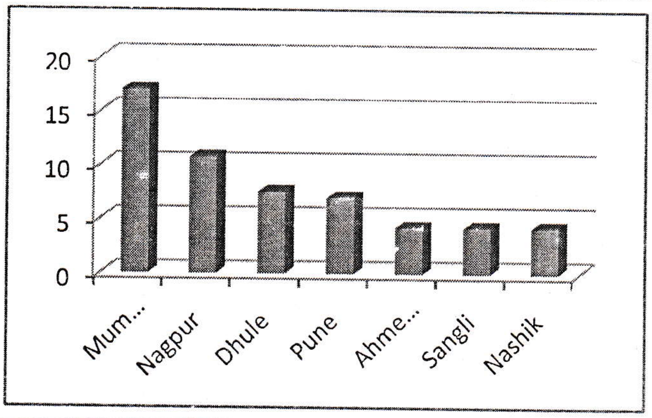
All India level

Name of Centre	Number of Students	Average Marks %
Kolkata	186	44.7
Delhi	121	38.7
Bangalore	39	26.5
Maharashtr a	1068	06.7



Maharashtra state

Name of Centre	Number of Students	Average Marks %
Mumbai	65	17.0
Nagpur	29	10.8
Dhule	29	7.54
Pune	547	7.02
Ahmednagar	125	4.28
Sangli	148	4.27
Nashik	125	4.25



The situation depicted through the histogram, is quite alarming. This situation in small towns in the districts is still worse.

An objective analysis of these representative facets of our educational scenario needs us to grasp the following reality.

When we say that the state of the affairs in Science Education is not satisfactory, it is required that we should define what is satisfactory. If we keep moving our goal posts our analysis would be certainly biased. The first question we need to ask ourselves is whether we have defined specific learning outcomes (SLOs) for our graduate program, and for each course and for each of the unit in the course? If such SLOs are explicitly defined are they known to the teachers, to the students and to the examining paper setters? If the answer is affirmative, it is expected that the students should have been evaluated keeping in mind the same SLOs. If then the students do well in the examinations so conducted and they do not do well in the SET or other examinations then it may mean that the SLOs for the other examinations (like SET, ET etc) are markedly different. This would mean that we are comparing apples with oranges or expecting a cricketer to do well in a golf tournament.

Assuming that no SLOs are clearly defined or communicated as expected in the above paragraph, it is still a fact that examinations do take place regularly with a pattern which can be deciphered if one goes through the string of published previous papers. Every examinee hoping to pass the paper directly or indirectly through peers undertakes such an exercise and prepares for the examinations accordingly. Such hidden curricula (including the SLOs) point to the expectations from the students. A comparison through such hidden curricula for the degree programs and that of the ET or SET should point to a difference in the approaches. There again we would be comparing oranges with apples and trying to compare the incomparable.

Thus (even assuming the system to be comprising of honest paper setters, honest teachers and honest students), as long as there are difference in the SLOs (expressed explicitly in published documents or implicitly though the practice of questions asked), there would be a difference in performances in the degree examinations and those at likes of ET or SET. As long as we do not pose the questions of the caliber of the SET or ET at our degree level examinations let us not expect that the examinees would do well in the examinations whose standard is inherently of a remarkably high quantum.

The reader would say that it would be indeed impractical if not impossible to achieve this overnight. There will be a massacre in the examinations and practically all the examinee would fail to attain the minimum grades.

We agree to this obvious response. There is a need to systematically and gradually update and upgrade all the components in the education: the program design, the curricula, the teachers, the questions in the continuous assessment (CA) as well those in the end examinations (EE).

We should not be shy of asking fundamental questions while designing the program. Not all the students would undertake a research position after completing the program. But there must be enough challenges for such gifted, motivated high achievers. The program should be devised and designed in such a way that the low, medium and high achievers should all participate in it with interest.

Learning a physics concept is a fairly complicated activity. It includes aspects of receiving instructions (being told, being informed) performing cognitive activities (like calculations, remembering fact, numbers, formulae) performing psychomotor activities (like performing a laboratory experiment) visualizing, assimilating with the personal experience or ideas from other contexts of physics or mathematics curricula, theorizing and many more. Individual students, according to their levels of competence and commitments participate in these activities in very different manners.

The outburst expressed by Dr. CNR Rao is, thus, not surprising and what he has not said explicitly is all known to experts. It has to do with the teaching methods used in the classroom. The high school students, college students learn (?) the subject in a passive manner. The lecture method used in classroom fails to motivate the students in achieving the learning goals because of lack in the interest on the part of teacher. This method, at the hands of an inept teacher, is often quite boring and prevents the students from learning the subject especially when the teacher imparting the knowledge is not well versed in the subject. (However, there is not anything inherently boring in the "chalk and talk" method. Effective communicators like Sal Khan (Khan, 2014) or Feynman Lectures (Feynman, 1964) of Physics have immortalized the physics teaching using the classic class-room lectures) However, Prof. CNR Rao has given a clue to solve the problem. *"Science is not about huge laboratories and making nuclear reactors. That was all technology. Science in real sense is in small labs".*

In fact, science is about asking questions and trying to find the answers. In the ancient to medieval periods in Europe, the most acclaimed philosophers-scientists like Galileo, Kepler and Plato wrote books in the format of dialogues. Whenever a proposition is placed before a reader, his mind assimilates that concepts and either accepts it as acceptable or doubts it. Such doubts are posed to the proposer of the concept in the dialogue. Such a style of communication has since lost its space as the education moved from classes to masses. There was no time for dialogues. We feel however that through modern means of communications using internet and social media, it is still possible to invoke this great form of teaching.

2. Science Learning through Modern Tools

It has been known and established with certainty that science can be learned much better if the theory is coupled with hands-on-activity. Science can be entertaining also if the learners learn the subject through Question-Answer sessions by experimentation, by interactive dialogues with the teachers. However, this is rarely done in practice and most of the places where science is taught by lecture only. As a result, the students are denied an opportunity to learn the subject with joy.

Nowadays, the computer especially internet has taken over and the things that were never thought possible are possible. The subject can be learned in an interactive manner, through simulation, audio-video display. The lecture of the experts in the subject can be viewed in the comfort of home. On-line courses free of cost are also available. The e-learning is available at the flick of a button. In fact the computers are revolutionizing the whole learning process and the benefits of this revolution are available to anyone who wants to learn.

There is no need to set-up big laboratory with expensive apparatus. The solar computers/tablets using modeling and simulations are bringing education to remotest corners of the world.

The active learning process involves the hands-on-activity, dialogs with teachers, interactive learning, discovery learning, exploratory learning, and participatory learning. The research (Willingham Daniel, 2013), indicates that the learning process whenever the learners do the activity first followed by passive learning methods learn much better than the first theory learning followed by hands-on-activity. This is contrary to what the learning pyramid (figure-1) Magennis and Farrell (2005), suggests. The learning can be implemented effectively so as to enhance the retention rate as well. The objective of the active learning can be very well achieved by taking into consideration learning pyramid. Reversing the order of passive teaching methods and participatory teaching methods would dramatically increase the retention rates in the pyramid.

To study and understand the topics in Emerging Trends in Physical Sciences, the college, universities must have trained manpower- teachers, research workers etc. To develop such manpower is a challenging task. Old methods of learning teaching are not shown to be useful. Passive teachings without hands-on-activities are shown to be grossly inadequate in handling the problem. One fortunately has the modern tools that are developed in last two decades, viz modeling, simulation, active learning, hands-on-activities, audio visual techniques, animations and virtual laboratories, etc. Lot of work has been done in USA and other places, Zollman (2002), Redish (2002), Weiman Carl (CWSEI Copyright © 2007-2011), have studied the problems and shown the methods of tackling the problem. In nutshell these workers have discovered that learning can be made effective and interesting if it is coupled with modeling & simulations and engaging the students in dialog form, in understating their requirement of the topics to be studies and solving their own problems as they learn the subject. The students are shown to be repelled by the passive teaching methods. These workers have found that if the subject is explained through modeling and simulation techniques the students will learn the subject in an interesting, stimulating manner.

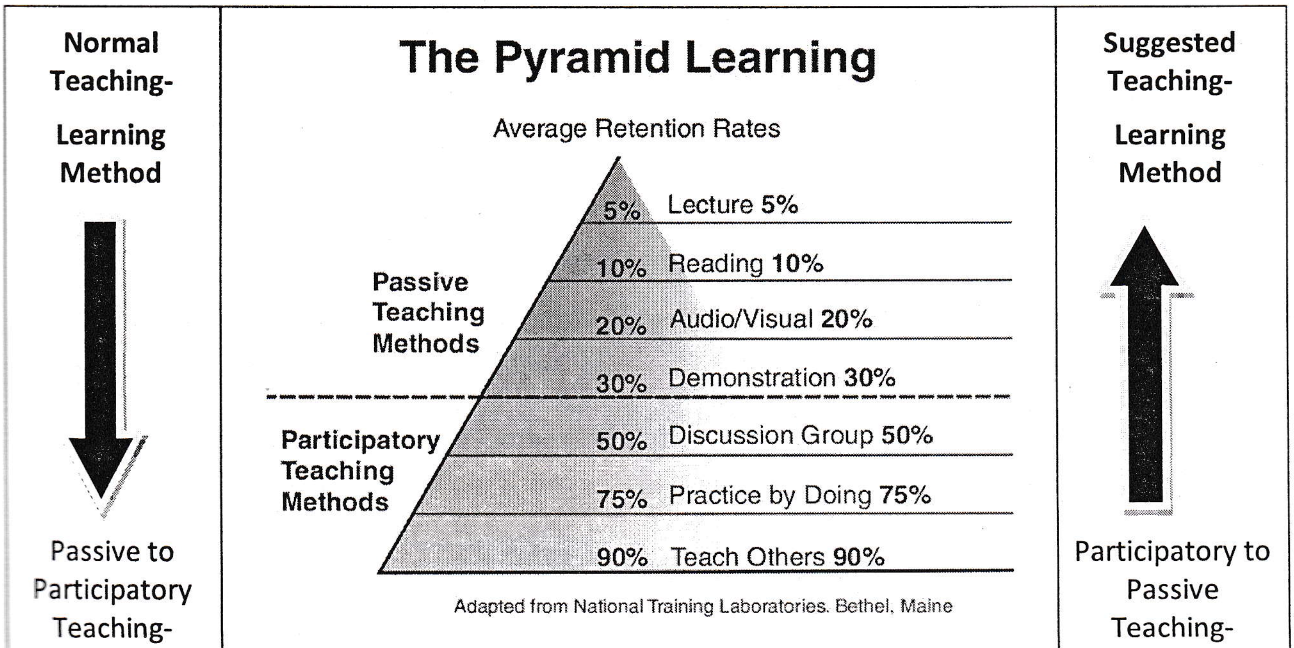


Figure-1

3. Modeling and Simulation

Modeling & Simulation (M&S) is getting information about how something will behave without out actually testing in real life. This may be a modern version of "Gedanken" experiments so effectively used by Einstein (1907) in explaining relativity and Neils Bohr in Quantum Mechanics (McKagan, Perkins and Wieman, 2008).

The emerging discipline of M&S is based on developments in diverse computer science areas as well as influenced by developments in System Theories, Systems Engineering, Software Engineering, Artificial Intelligence, and more. This foundation is as diverse as that of engineering management and brings elements of art, engineering, and science together in a complex and unique way that requires domain experts to enable appropriate decisions when it come application or development of M&S technology. Modeling and Simulation is a discipline for developing a level of understanding of the interaction of the parts of a system, and of the system as a whole. The level of understanding which may be developed via this discipline is seldom achievable via any other discipline.

The M&S can be effectively used for studying, learning of Quantum Mechanics (QM), which is the base of all emerging branches of modern physical sciences and the life sciences also.. The students whether they are graduate level or postgraduate level students must get proper understanding of the subject. In fact, QM is regarded as the language of modern sciences.

Even in QM, the basis dynamical law is "Schrodinger Equation". The beginning students of QM are quite perplexed by the new concepts, mathematical techniques, language of the subject (e.g. Eigenvalues and Eigenfunctions, Wave functions etc.) and the passive teaching methods are regarded to be quite inadequate to overcome students' difficulties.

If the subject like QM can be taught using modeling and simulation techniques, with particular emphasis on Schrodinger equation, students may be learn QM without getting bogged down in complications of matrix algebra, differential equations, state functions etc.

The M&S can be used to visualize the abstract concepts of QM, such as tunneling effect, potential wells, potential barriers, radio activity, etc.

The present author (1) has studied this method of imparting instructions to the students in his Ph. D. thesis (Joshi, 2013), "Computer Assisted Instructional Material for Quantum Mechanics (CAIM-QM)". The present paper lists the M&S methods used in teaching T.Y. B.Sc. and Postgraduate Physics students. Number of workshops was held in QM for the students. We concentrate in this paper on the Schrodinger equation which is essential to understand *'Tunneling Effect'* (the Schrodinger equation which is symbolically written as $H\Psi = E\Psi$, where H is the Hamiltonian (or Energy) operator, E is the eigenvalue and Ψ is called the eigenfunction or state of the system.

The workshops must also indicate the effectiveness of the instruction methods. The techniques developed by Bao, L. (1999) at the University of Maryland in USA have been used to this end. The method of Bao L. uses the methodology of QM, viz. density matrix, eigenvalues, eigenfunctions and model plane plots. This method will be explained later.

3.1 The Beginning Pre-Test

At the beginning of the workshop, a pre-test was conducted using multiple choice single response (MCSR) questions with an objective to gauge the understanding level of the students. MCSR contains five options in which one option is correct (expert model). The remaining distractors include combination of one or more misconceptions and a null model state. The misconception model is triggered when a given option chosen by a student does not match with the scientifically correct concept. If a student selects an irrelevant idea for a given context or even does not select any choice, then it is null model state.

An example of MCSR question (McKagan, Perkins and Wieman, 2008) asked during the test is given in Figure-2. In this Figure, the electrons are free to move around within the wire, the potential energy of an electron is constant everywhere inside the wire (which we arbitrarily set to zero). The electrons are bound to the wire and require energy to escape because of the work function of the metal; their potential energy outside the wire will be a larger constant, so that the potential energy of the system is well approximated by a step potential. According to classical physics, answer would be C. It is misconception

Q. An electron is traveling through a very long wire, approaching the end of the wire as shown in figure

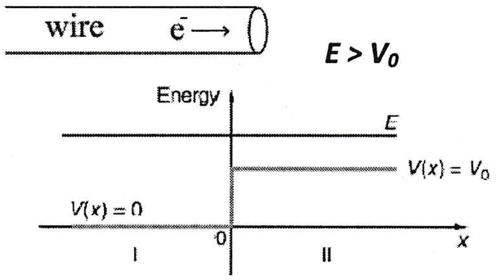


Figure-2.

If the total energy E of the electron is greater than the work function of the metal, V_0, when the electron reaches the end of the wire, it will...

A. stop.
B. be reflected back.
C. exits the wire and keeps moving to the right.
D. either be reflected or transmitted with some probability.
E. exits the wire and re-enters repeatedly.

Similar type of MCSRs are asked with different conditions like $E > V_0$, $E = V_0$ and $E<V_0$.

Another example of MCSR question in context of potential well and potential barrier (for condition $E<V_0$) is shown in Figure 3.

(a) Potential Well

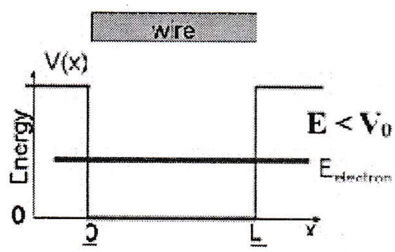


FIGURE 3(A) A square well with width L and height V_0 represents a wire with length L and work function V_0.

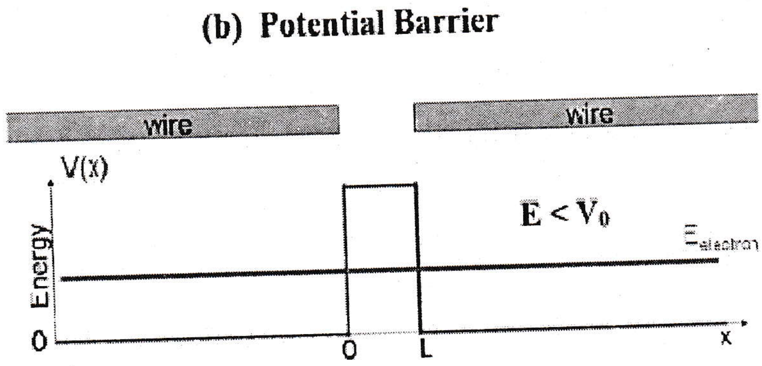


Figure 3B A square barrier with width L and height V_0 represents two long wires with work function V_0 separated by an air gap with length L.

Each MCSR question is given with energy diagram. The student has to sketch the wave function. He is expected to select the option of his choice and state the reason for it.

3.2 The Workshop and Post-test

After test, an information booklet and assignments on related topics were distributed to all students. The post graduate students in the Indian environment (namely Pune University) are required to undergo both theory and practical course as a part of curriculum. The students were divided in two groups as per their practicals batches in regular course. One batch was treated as an Experimental group (EG) and another one was treated as a Control group (CG). Experimental group was trained using CAIM-QM, by performing *PhET* simulation experiment (University of Colorado (2009), (Figure 4). While performing the experiments the students took readings and plotted various graphs as per the CAIM-QM instructions. Responses of both groups (Control group and Experimental group) were collected using open-ended questions and personal interviews. Difficulties raised by the students were taken into account and answered.

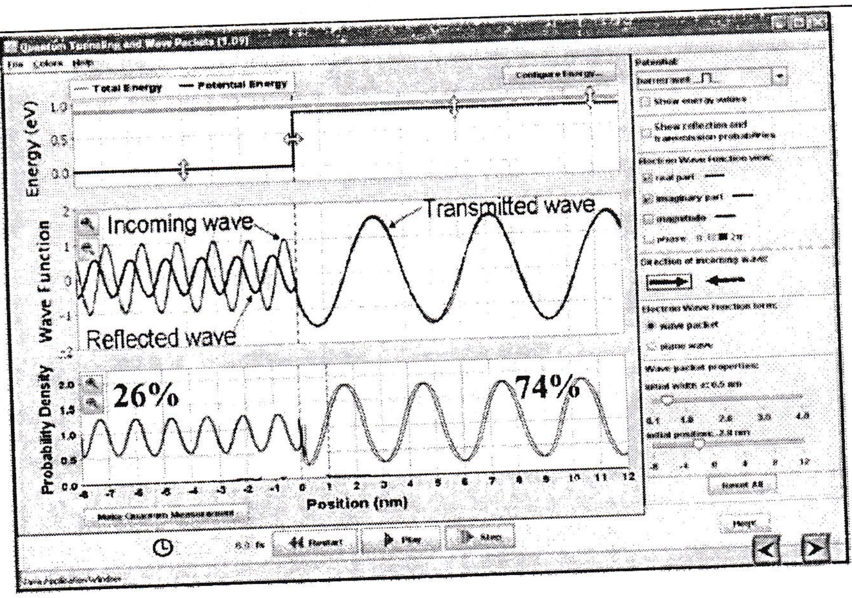


Figure-4. Screenshot of *PhET* 'Quantum Tunneling' experiment.

For further analysis, assignments given to all students at the beginning of the workshop were collected immediately after the end of the workshop. All these feedbacks are utilized for improvement of CAIM-QM. Post-test was conducted by adding some extra MCSRs in the pre-test questionnaire. In pre-test energy diagram for each question was given (for example Figure 2, 3a and 3b) and the students were asked to sketch the wave function. In post-test energy diagram was not provided, but the students were asked to sketch both the energy diagram and wave function. They were expected to select the option of their choice and give the reasons for their choices in both tests (pre-test and post-test).

As discussed above modern analysis technique like Model Plane Plot gives valuable inference regarding class model state. Therefore Model plane plot on Tunneling Effect with different conditions is discussed.

4. Probing Instruments and Analysis Tools: Lei Bao Method

As in quantum mechanics, the 'state' of a system is described by an abstract vector. A vector (e, m, n) represents a state of a student. S/he may apply a model or method (a) which we would 'expect' an expert to employ when faced with a similar situation (E state), or (b) which is not appropriate to the given situation posed in the given problem we say that s/he has evoked a "misconception state" (M state), or (c) s/he has evoked an irregular ideas then it is a "null model state" (N state) for the particular problem.

In such a case we may consider a k^{th} student response who has been asked 'q' number of MCSR questions with 'r' choices for each of them. Suppose that s/he answers e number of questions correctly (Expert state); answers m number of questions not properly internalized (exhibiting Misconceptions) and answers n number of questions in wrong manner (exhibiting Null state). Then we can say that the probability of her/his in E state is e/q, while the probability of finding her/him in M state is m/q and that for the N state is n/q, with the condition q=e+m+n.

In quantum mechanics we speak about the probability amplitude vector such that the norm (or square) of such vector is proportional to the probability of finding the system in that state.

For a single student labeled k who has been asked q questions of multiple choices, the student state vector can be constructed as

$$u_k = \begin{bmatrix} \sqrt{e/q} \\ \sqrt{m/q} \\ \sqrt{n/q} \end{bmatrix} = \frac{1}{\sqrt{q}} \begin{bmatrix} \sqrt{e} \\ \sqrt{m} \\ \sqrt{n} \end{bmatrix}$$

The k^{th} student model vector is represented with $|u_k\rangle$, where k = 1, 2, 3... N and the student 'density matrix' for k^{th} student are defined as:

$$D_k = |u_k\rangle\langle u_k| = \frac{1}{\sqrt{q}} \begin{bmatrix} \sqrt{e} \\ \sqrt{m} \\ \sqrt{n} \end{bmatrix} \frac{1}{\sqrt{q}} \begin{bmatrix} \sqrt{e} & \sqrt{m} & \sqrt{n} \end{bmatrix}$$

$$= \frac{1}{q} \begin{bmatrix} e & \sqrt{em} & \sqrt{en} \\ \sqrt{me} & m & \sqrt{mn} \\ \sqrt{ne} & \sqrt{nm} & n \end{bmatrix} \qquad (1)$$

4.1 Class Density

Matrix

We can construct class density matrix *D,* by taking average of student density matrix for the whole class comprising of $\mathcal{N}$ students as

$$D = (1/\mathcal{N}) \sum_{k=1}^{N} D_k \tag{2}$$

The Student Model Density Matrix D_k retains the structural information on individual student responses with respect to different physical models. Similarly, the class model density matrix *D* stores important structural information about the class of students.

4.2 Analysis of the Data

To analyze the data, one must calculate student density matrix from responses of a particular student and solve it to get its eigenvalues, and its eigenfunctions. With the help of above information one may draw a model plane plot. Model plane plot is the graphical representation of student model states. Student model states will decide the product of dominant component of eigenvalue σ_μ^2 and square of the corresponding eigenvector v_μ^2 of the class model state. This is shown in figure-5 with the coordinates ($\sigma_\mu^2 v_{1\mu}^2$, $\sigma_\mu^2 v_{2\mu}^2$) on model plane plot.

Tunneling Effect

Point ($\sigma_\mu^2 v_{1\mu}^2$, $\sigma_\mu^2 v_{2\mu}^2$)	**Pre-test**	**Post-test**	
		CG	**EG**
Expert model	0.18	0.32	0.49
Misconception	0.34	0.32	0.16

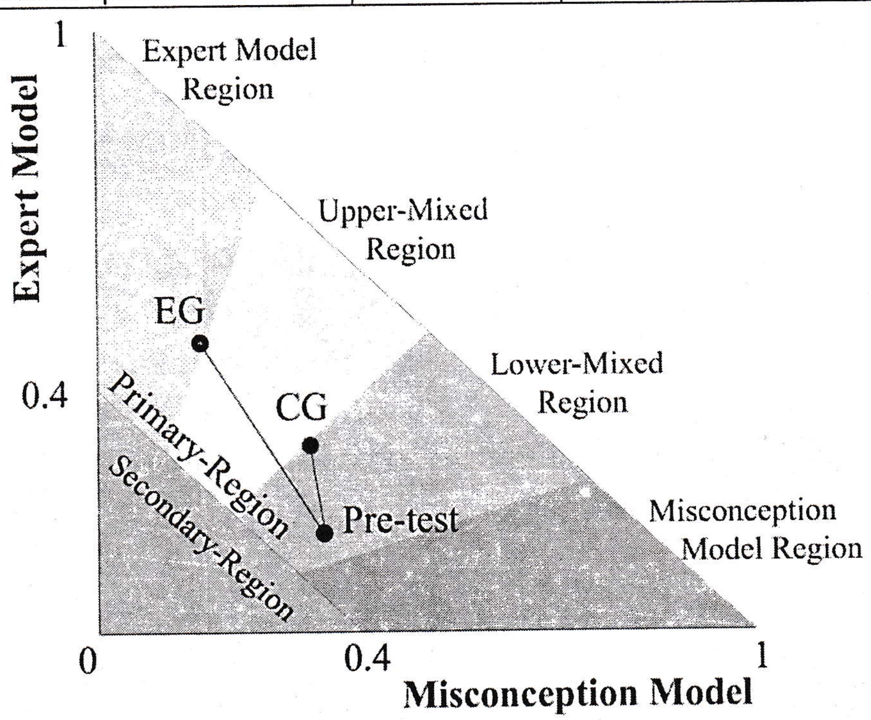


Figure-5.

5. Observations

- From figure-5; it is observed that class model state of pre-test is in Lower-Mixed (LM) region. It indicates that before training students are confused regarding the concept of 'Tunneling Effect'.
- Post-test of Control Group (CG) is shifted on boundary of Lower Mixed-Upper Mixed (LM-UM) shows improvement in CG but they are not shifted in expert model region. Therefore traditional teaching-learning method is requires some modifications for improvements of CG.
- Using modern technique of M&S; Experimental Group (EG) is shifted in Upper Mixed-Expert Model (UM-EM) region showing satisfactory change. Repetitive training is needed to shift EG in the Expert Model (EM) region.

An application of Schrodinger equation to tunneling effect is very interesting. It allows you to study the QM and its beauty without getting bogged in complex mathematics. The modern tools- computers make this study almost effortless. The main beneficiaries are the student of QM of Physics who must acquire mastery of the subject and also the students of other disciplines such as life sciences- who must get working knowledge of QM in understanding of their subjects. The tools which are used nowadays- animation, audio video clips, and virtual laboratories stimulate the interest of even non-science majors in the range of topics which can be studies and that too with great deal of excitement. Gone are the past days where learning was only through passive methods.

6. Conclusions

The methods used here are only for the illustrative purposes. The information contained in Model Plane Plots is very rich in context. It goes a long way to indicate whether the teaching had been effective or whether improvements in teaching methods are called for. It also indicates whether the students benefitted from the instruction imparted. The method is subject- independent and can be used in other branches of studies – such as psychology, economics, language teaching, or any of newly emerging branches of studies- mental and moral sciences and even management sciences included.

References:

1. Bao, L. (1999). *Dynamics of student modeling: A Theory, Algorithms and Application of Quantum Mechanics.* Ph. D. Thesis, University of Maryland, USA.
2. Einstein (1907). Retrieved Sept. 8, 2014, from http://www.britannica.com/EBchecked/topic/1252186/Gedankenexperiment
3. Feynman Richard (1964). Retrieved Sept. 8, 2014, from http://www.feynmanlectures.caltech.edu/
4. Joshi, P. P. (2003). *The Design of Instruction Manual for Assembly of Electronic Toys for Std. VIII & Std. IX High School Students.* M. Phil. Thesis, Y. C. M. Open University, Nashik, Maharashtra, India.
5. Khan Sal (2014). Retrieved Aug 12, 2014, from https://www.khanacademy.org/

6. Magennis and Farrell (2005), Retrieved Oct. 22, 2014, from http://www.learningandteaching.info/learning/myths.htm

7. McKagan, S. B., Perkins, K. K. and Wieman, C. E. (2008). A deeper look at student learning of quantum mechanics: the case of tunneling. *Physical Review Special Topics:* PER, 4, 020103.

8. McKagan, S. B., Perkins, K. K. and Wieman, C. E. (2008). Why we should teach the Bohr model and how to teach it effectively. *PhysRev: ST Phys Ed. Rsrch.* 4, 010103.

9. PhET, University of Colorado, (2009). *Interactive Science Simulations* http://phet.colorado.edu/index.php [viewed 21/8/2009].

10. Redish, E. F. (2002). Pedagogical Resources on the Web for Teaching Physics: *Physics Education Resources.* Retrieved April 28. 2011 fromhttp://www.physics.umd.edu/perg/ecs/phe.html

11. Savitribai Phule Pune University, entrance test to the admission to M. Sc. Physics, (2014). Retrieved Aug 17, 2014 from http://unipune.ac.in/pgadmissions/

12. Times of India (Aug 5, 2014). http://timesofindia.indiatimes.com/home/education/news/Science-taught-in-schools-is-most-boring-outdated-CNR-Rao/articleshow/39695397.cms

13. Wieman, (CWSEI Copyright © 2007-2011). The Carl Wieman Science Education Initiative (CWSEI) is a multi-year project at The University of British Columbia [Electronic version]. Retrieved Aug 17, 2011, from http://www.cwsei.ubc.ca/

14. Willingham Daniel (2013). Retrieved Oct. 22, 2014, from http://www.washingtonpost.com/blogs/answer-sheet/wp/2013/03/06/why-the-learning-pyramid-is-wrong/

15. Zollman, D. A., Rebello, S. N. and Hogg K. (2002). Quantum Mechanics for Everyone: Hands-On Activities Integrated with Technology. *American Journal of Physics 70* (3), 252-259.