Indian Association of Physics Teachers
A Study of the Pedagogies, Programs and Policies of Physics Education

Thesis submitted to the Jawaharlal Nehru University
for the award of the degree of

Doctor of Philosophy

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DECLARATION

I hereby declare that the thesis *"Indian Association of Physics Teachers: A Study of Pedagogies, Programs and Policies of Physics Education"* submitted by me at Zakir Husain Centre for Educational Studies, School of Social Sciences, Jawaharlal Nehru University, New Delhi, for the award of the degree of Doctor of Philosophy, is my original work and has not been submitted in part or in full for any other degree in any University.

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CERTIFICATE

We, hereby, recommend that the thesis be placed before the examiner(s) for the award of the degree of Doctor of Philosophy of Jawaharlal Nehru University.

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Introduction

Science education the world over has witnessed reforms and renewal from time to time. As reflected in the policy documents and the programmes of action, emerging socio-economic needs as well as disciplinary developments have necessitated the renewal of science education. India too has confronted the need to renew science and physics education. Though national agencies such as National Council of Educational Research (NCERT) and University Grant Commission (UGC) have been playing an active role in this regard, the immensity of the task demands the involvement of several agencies on a long term basis. The coming together of physics teachers from colleges, universities and schools from across the country under the umbrella of the Indian Association of Physics Teachers (IAPT) in 1984 was one of such response. This thesis is an attempt to understand the work carried out by IAPT on physics education.

1.1 The Context of the Renewal of Science Education in India

Changes in science education are driven by factors, both, internal and external to the discipline. On the one hand, the need for socio-economic development creates the demand for advancements in scientific literacy and highly specialized and cutting-edge knowledge in science and technology; on the other, disciplinary advancement in the allied disciplines offer insights in reconceptulising and re-framing science education. Consequently, the interplay of these forces, drive the disciplinary evolution of science education and related applications (DeBoer 1991, 2000; Duschl 2010).

As India is seeking to establish itself as a knowledge power, it is essential to build on its science and technology base (Department of Sciene and Technology [DST], Government of India 1958, 1983, 2003). This demands a reform of the educational system in the sciences from the elementary to the tertiary stage (ME, Government of Inida 1966; MHRD, Government of India

1992, 29). Apparently, the developments in this sector could pave the way for an increase in the quality and quantity of research in the sciences, which then can play a critical role in building excellence in science and technology. It is argued that a good foundation when established in science and technology will propel economic growth, and raise the living standards of the people (NKC 2009, 189).[1]

Indeed, the developmental strategy of a nation is coupled to the quality and standards of science education. According to the Education Commission (ME, Government of India 1966, 1), "The destiny of India is now being shaped in her classrooms". However, contrary to the policies enunciated over the few past decades, a shift in student enrollment in the sciences at the secondary and undergraduate levels has been observed (Garg and Gupta 2003).[2] A study suggests that with students increasingly opting for arts, commerce and professional courses, and the appearance of more lucrative opportunities in related professions, there has been a decline in students enrolling in pure mathematics and science courses. As a consequence, there has been a decline in the enrollment in science courses (NCAER 2005, 5-23).[3]

Leading academics involved in higher education and research in the sciences have been expressing great concern on the quality of science education in the country. The general view is that the standard of science education in all respects has declined rapidly and alarmingly. The damage inflicted on science students is not limited to science education and research at higher levels but begins at the elementary stage. It is at the earliest stages of schooling that curiosity, self-confidence and enthusiasm and eagerness to learn are killed

[1] The report of the National Knowledge Commission (NKC) (2009) recommends the creation of a critical mass of science professionals by revamping the science and mathematics education in the country.
[2] The study cited is confined to Delhi.
[3] National Council for Economics and Applied Research (NCEAR)(2005) was commissioned by the Indian National Science Academy (INSA), to survey three interrelated issues—the status of science and engineering education, utilization patterns of human resources and public attitudes towards science and technology. The report highlights an overall decline of enrollment in the sciences across the nation.

(Bhide et al. 1991; IAS 1995; INSA and IAS 2006; INSA 2010).[4]

Can India produce a globally competitive scientific community and scientifically literate populace under these circumstances? The National Knowledge Commission (NKC 2006, 191) posed the question of declining interest in mathematics and sciences and recommended improvements in pedagogy, evaluation, curriculum, careers, and infrastructure. Similar concerns have been reiterated by the Indian Academy of Science (IAS 1995) and Indian National Science Academy (INSA 2010, 12-13). Moreover, reforms in science education need to be tuned to the general shift throughout the world from 'Science-for-the-Few' to 'Science-for-All' as an increasingly globally connected world would require that all educated citizens become science and mathematics literate (Seymour 2001).

1.2 Physics Education: Problems and challenges

Progressive changes in the teaching and learning of science at various levels need to be made to respond to aforementioned demands. This leads us to raise the question: What is the prevailing scenario in science education and is it problematic? In general, introductory and undergraduate physics courses are presented as the compendium of factual knowledge. The major portion of the content comprising concepts, laws, principles and theory is packed and presented through mathematical formula and equations. A well-structured mathematical formalism is used to instruct students apply theory to solve problems. The validity of the theory is established by demonstration and verificatory experiments (Hestenes 1987; Adkinson 2004; Kurki-Suonio 2010). Contrary to the intended goal, this mode of instruction proved unproductive in fostering a conceptual understanding or scientific reasoning. Problem-solving becomes an exercise in manipulating mathematical formulas and

[4] Bhide Committee constituted by the Planning Commission in 1989 presented a position paper in 1991 to restructure the system of science education at the tertiary level. The suggestion was to develop a three-tier system for science education – catering to the needs of the most talented (0.5%), relatively advanced ones (16%) and the average student. The committee came up with some additional suggestions. The establishment of the Indian Institutes of Science Educations and Researches (IISER) in different parts of the country in last decade was one of the recommendations of the committee.

equation and lacks in connecting with the real physical phenomenon outside the classrooms. Thus advancement of physics education rests on the reconceptualisation of the existing pedagogical practices (Hestenes 1987; McDermott 1993; Redish 1994; DeHaan 2005; Taber 2006).

Why does this scenario prevail? One of the ways it can be understood, according to Wolpert (1992), is to understand how unnatural science is. According to him, science is a special mode of thought and is unnatural for two main reasons. Firstly, it is not constructed on a common-sensical basis. This means that every-day common sense or what he calls 'natural thinking' does not offer insight into scientific ideas. In contrast to common sensical inspection of physical phenomenon in day-to-life, science is counter-intuitive. Secondly scientific investigations demand unfailing commitment to guard against the pitfalls of 'natural thinking'. Contrary to error prone nature of common-sense, scientific thinking is built upon rigorous observation constructed around experimental processes and its conversion into mathematical ideas (ibid x-xii). Keeping in view the strict demarcation between these two forms of thinking, the direct introduction of scientific ideas from outside becomes problematic. Before students find themselves ready to grasp scientific ideas, their common-sense ideas need to be confronted head-on and students need to unlearn or integrate these ideas with the scientific ones (Freedman 1996).

Examining teachers' view of pedagogy and reorienting them is another issue that needs to be addressed. In spite of falling short of a valid and efficient pedagogy, teachers continue to teach the way they were taught (McDermott 1990). Rather than conducting scientific analysis, they happen to rely on their limited view of the subject matter and perception of students. Most of physics teachers become eager not only to transmit knowledge and skills they have accumulated after years of intellectual efforts but also their enthusiasm to students. To save students from similar struggle, teachers often pursue a top-down and general to particular approach of teaching. Students are not actively and thoroughly involved in the process of abstraction and generalisations (Hestenes 1987; McDermott 1991, 1993).

Despite the fact that contemporary science education is replete with theory-laden insights, practice persists. The tradition built around positivist pedagogy dominates the scene (Pitt 1990; Redish 1994; Jenkins 1996). The textbooks in this tradition propagate the idea of theory-free-data, and neglect the role of the scientific community in validating knowledge (Hodson 1985; Duschl 2008). Often, teacher tends to think of students as their younger versions. While in actuality only a few of them may fit the bill. A small number of these students learn successfully from lectures, textbooks and problem-solving exercises because they constantly question their comprehension, confront their difficulties and persist to resolve them. In simple terms they rediscover physics mainly because of their own efforts. On the other hand, despite the best efforts of teachers large segment of the students never reach their optimum potential (Hestenes 1987; McDermott 1993). As a matter of fact there is a growing realization amongst physics faculties that a significant gap exists between what they believe they are teaching and what students actually learn (McDermott 1990, 1991; Rebello and Zollman 2005; Wieman 2008).

As the thrust for a scientifically literate citizenry is on the rise, the physics education community is endeavouring to make physics education effective for all the segments of the student population. Equipped with a clear apprehension of scientific ideas, they propose to train students make wise decisions on various socio-scientific issues like climate change, genetic modification and energy requirements etc. In order to become economically productive members of society, they need to be well-trained in problem-solving skills lying at the interface of science and technology. Indeed it becomes imperative to renew physics education and help every student learn physics optimally (Wieman and Perkins 2005; Wieman 2008).[5]

1.3 Physics Pedagogy: Need of a Reflective Practice

Is there something fundamentally wrong with the way the teaching of physics is practiced in schools and colleges? Is this the case with physics only or does it hold true of other science disciplines? Suggesting problem exists all through higher education, Boyer (1990) proposes a 'scholarship of teaching' to replace the traditional notion of teaching. According to him, a university teacher defines her profession in terms of research in her discipline and assigns teaching a lower status. While research is carried out as a scientific activity, teaching is left to the diktats of teachers' perception. Terenzini and Pascarella (1994) reinforce the view by stating that higher education is captivated by the myth that "good researchers are necessarily good teachers". The problems encountered in teaching are considered as deficits to be fixed, diagnosed and remedied. This does not suffice to resolve the problem. Thus the need to take a sharp departure from the traditional pedagogic practice—from a perception driven exercise to one of an ongoing investigation or scholarship of teaching (Bass 1998; Hutching 2007). Scholarship for teaching constitutes the forth component of Boyer's scheme of scholarships--discovery, application, and integration of knowledge in the discipline being the other three components. Rather than exclusive, these scholarships overlap with each other and a synergic exchange among them helps academics excel in each of them (Boyer 1990, 16). Like disciplinary research, 'Scholarship for Teaching' needs to be continuously debated, discussed, empirically researched and shared as a scholarly act (Shulman, 2004).

Schon (1995) provides another important perspective which the reflective physics education community might have to deal with. He argues that doing things in a reflective way demands a new institutional epistemology, a new way of knowing and documenting evidence. He points out the presence of the two mutually exclusive aspects of the problems of teaching:

[5] Wieman won the physics noble for the year 2001.

> In the varied topography of professional practice, there is a high, hard ground overlooking a swamp. On the high ground, manageable problems lend themselves to solution through the use of research-based theory and technique. In the swampy lowlands, problems are messy and confusing and incapable of technical solution. ...... Nearly all professional practitioners experience a version of the dilemma of rigor or relevance, and they respond to it in one of several ways. ....The dilemma depends, I believe, upon a particular epistemology built into the modern research university, and, along with this, on our discovery of the increasing salience of certain "indeterminate zones" of practice -- uncertainty, complexity, uniqueness conflict -- which fall outside the categories of that epistemology....."technical rationality," is that practice is instrumental, consisting in adjusting technical means to ends that are clear, fixed, and internally consistent, and that instrumental practice becomes professional when it is based on the science or systematic knowledge produced by schools of higher learning.....Technical rationality fostered a separation between research and practice. ... -- finds little place to stand in the turbulent world of practice, which is notoriously uncontrolled, where problems are usually ill-formed, and where actors in the practice situation are undeniably "interested."[6]

Furthermore, knowing in practice is ordinarily tacit and day-today work of the professional practitioners reveal judgments, skills and a pattern of tacit knowing-in-action (Ibid.). Thus, practitioners need to think of practice not only as the site for the application of knowledge but also its generation. In other words, they need to ask not only how they can apply the results of academic research, but also what kind of knowing is already embedded in competent practice.

Is there a possibility for merging the two kinds of knowledge sources just discussed in physics education? It is notable that probably physics happens to be one of the few disciplines where pedagogical research since 1970s has already entered into practice. However, in spite of the lead taken, it is not as widespread in practice as desired (Docktor and Mestre 2014). McDermott (1998), one of the pioneer in the field, contends that: “Unless we are willing to apply the same rigorous standards of scholarship to the issues related to learning and teaching that we regularly apply in more traditional research,

[6] Donald A. Schon, “Knowing-in-action: The new scholarship requires a new epistemology,” *Change: Journal of Higher Learning*, 27, no. 6 (1995): 1-2.

the present situation in physics education is unlikely to change"(8). These views appear to have found wide spread support from the physics education community world over (Anderson et al. 2011). Nigavekar (1996, 123-124) presses for structural reform so that research has an impact on teaching, and publishing about teaching. Proceeding on similar lines, Wieman (2008) speaks of the similarity between the knowledge which science education researches have created and the tacit understanding a practitioner has in research arena. He states:

> Much of educational and cognitive research can be reduced to this basic principle: People learn by creating their own understanding. That does not mean, however, that they must or even can do so without assistance. Effective teaching facilitates that creation by engaging students in thinking deeply about the subject at an appropriate level and then monitoring that thinking and guiding it to be more expert-like. That is precisely what occurs with graduate students working in a lab, focusing intently on solving real physics problems. After a few years in that environment they turn into experts, not because there is something magic in the air in the research lab but because they are engaged in exactly the cognitive processes required for developing expert competence.[7]

Redish (1994) appears to acknowledge the complexity of tacit knowledge embedded in practice and calls for moving beyond the current understanding of the learning of physics: "The issue of how to teach physics is a difficult one: the attempt of a naive student to build a good understanding of physics involves many intricate processes over a long period of time. These processes tend to be much more complex than those most cognitive scholars have addressed." (797). On the contrary there is a strong view among physics education researchers that the majority of practitioners have not systematically attempted to understand students' learning processes in their discipline (Belcher 1996; McDermott 2001; Wieman 2008, 64; Henderson, Finkeltein and Beach 2010). Apparently in addition to the present understanding made available through educational research, physics teachers (as practitioners in their discipline) might have a characteristically different

[7] Carl Wieman, "Science Education in the 21st Century: Using the Tools of Science to Teach Science. Forum for the Future of Higher Education (2008): 63.

but useful perspective on the nature of physics education. Hestenes (1987, 3) contends that besides the present emphasis on cognitive insight into students' pre-scientific conceptions a reconceptulisation of the structure of knowledge is inevitable. The structure of knowledge comprises both factual and procedural components. Factual knowledge consists of models, theories and empirical data while procedural knowledge consists of strategies, tactics, and techniques for developing, validating, and utilizing factual knowledge. Thus it is not pedagogy in traditional sense but the pedagogical content knowledge (PCK) i. e. representation of content in teachable form that needs to be reconstructed (Shulman 1986).

Perhaps physics education researchers (PER) need to preserve and cultivate close connections with the traditional physics community, both to further the unique contributions made by physicists to the understanding of the learning of physics and apply the results of PER colleges and universities (Beichner el al. 1995; McDermott 2001; Heron and Meltzer 2005). Loughran (2002) suggests that this inherent difference in experiences and perspectives among physics education researchers and practitioners can enhance their reflective practice. It is argued that the incorporation of students' perspectives can effectively be achieved not just by practicing the traditional mode of teaching, but by adopting the practice of 'scientific teaching' that is not only informed by research conducted in experimental settings but also by action research on the practice itself (Hestenes 1979, 1998; McDermott 1998; Redish 1999; Wieman 2008).

1.4 Role of Learned Societies in Science Education

Historically, scientific societies have played a significant role in science and science education. British Association for Advancement of Science (BAAS) founded in 1831 served as a model for societies founded in other parts of the world (Sen 1991). American Association of Advancement of Science (AAAS) established in 1848 in USA and the Indian Association for the Cultivation of Science (IACS) founded in 1876 was amongst the prominent societies which were modeled on BAAS (Lourdusamy 2003, 390). Though IACS was originally established with the objective of facilitating advancement in original research, its main efforts during the initial years of its existence were directed towards the development of science teaching at venues outside and independent of the university (Sen 1991, 333). On the other hand, in the course of time the AAAS went through a differentiation in its structure and, new societies oriented specifically to the needs of specific disciplines, for example chemistry, mathematics and physics emerged (AAPT History n. d.). Nevertheless, AAAS continues to promote science and initiate new debates in science education. For instance, in 1989, 1993 and 2001, it prepared a policy document, "Science for All Americans" focusing upon the shift in the goals of science education from preparing future scientists towards the education of the future citizens (AAAS 1989, 1993, 2001).

American Association of Physics Teachers (AAPT), was founded in 1930, primarily with the purpose of providing a platform for the physics fraternity for sharing research concerns as well as responding to problems and developments in physics education in colleges and universities. Since 1950s, it has been playing an instrumental role in transforming physics education with support from the National Science Foundation (NSF) (AAPT History n. d). The extension of support from the pre-collegiate to college level physics was promoted both within and outside the American Association of Physics Teachers (AAPT), particularly by the Massachusetts Institute of Technology (MIT) that had, already established the Physical Science Study Commission (PSSC) (Finlay 1962/1992). The Commission on College Physics (CCP) was formed in 1960 with an aim to bring the resources of the community of physicists to the task of improving physics education (AAPT 1964).[8]

In 1960, AAPT in collaboration with United Nations Educational, Scientific and Cultural Organisation (UNESCO) initiated the formation of a similar body at the international level. Later in 1960, the International Commission on

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[8] History of American Association of Physics Teachers (AAPT History) see www.AAPT.

Physics Education (ICPE) came into being. Since then, with the initiatives of the commission, some thrust areas of physics education have been identified. For example, curriculum development has acquired a research-base that incorporates the models of students, learning process and instruction coupled with suitably designed instruments for assessment (ICPE 2001; Jolly 2002).

Considering the need to cooperate with the university physics teachers in Asian countries, UNESCO in 1981 supported the formation of Asian Physics Education Network (ASPEN). The objective was to draw upon the work of the international physics education community to upgrade the content and methods for physics teaching in Asian contexts. Interactive Physics Teaching, Active Learning Approaches and the use of multimedia in physics teaching are some of the activities associations have been engaging with in recent times (Jolly 2002).

In 1999, acknowledging the role of the physics education research community within AAPT, the American Physical Society (APS) approved 'research in physics education' as a sub-field within physics. A Physics Education Research (PER) Group has been established to promote the development of the field and enhance the dissemination of PER results to the broader physics education community through workshops, teacher training and other means (McDermott 2001). AAPT is seen as a platform for promoting physics education research with the support of a worldwide network of University-based physics education research groups. This world-wide community of researchers reaches out to a wide variety of forums for presenting and publishing physics education research.

1.5 Science Education in India

National Council for Educational Research and Training (NCERT) since its inception in 1961 has been working on the development of curricula for school education, including policy formulation and implementation, textbook production and teachers' training (NCERT 2011). Besides this, most of the states have their own State Councils of Educational Research and Training

(SCERT). Similarly, the University Grants Commission (UGC) and different universities spread across the country cater to the needs of higher education. However, considering the nature and scale of the problems in science education, the efforts carried out by these agencies do not suffice. The other stake holders in the field need to involve themselves in advancing the cause of science education (Kumar and Nigavekar 1994).

There are signs that the science education community in India is responding to problem. Hoshangabad Science Teaching Programme (HSTP) was inaugurated in 1972 jointly by the Friends Rural Centre and Kishore Bharati. These groups convinced government to allow them the freedom to run a science teaching programme for elementary classes (6 to 8th) (HSTPG 2002). Observations and experiments were employed to enrich the phenomenological experiences of students that had hitherto been given a miss by conventional pedagogy. Subsequently, analysis and discussion led work on the processes of concept building (Saxena and Mahenderoo, n. b). Years of experience in the field brought about the realization that a good curriculum must not only be responsive to the demands of the discipline and to the cognitive development of children, but must take account of the capabilities of the school teachers who have to engage with students in the classroom. As a result, over the years HSTP has been able to usher in a new discourse on science education in the country, organically linked to the experiences of children (Mukherjee et al. n. d.).[9] This formed the basis for developing the National Curriculum Framework (NCF)-2005 of the NCERT – an acknowledged contribution of the HSTP (Raina 2011). Having offered an alternative perspective, HSTP has also its share of criticism. For instance, Saxena and Mahenderoo (n. d) argue that it’s thrust on experiment and observation as the only valid way to learn science is problematic. There are other modes of knowledge construction as well where experiment as such is not feasible. They have suggested revisiting philosophy of science and benefit

[9] See the National Curriculum Framework-2005 (NCERT 2005).

from the insights therein.

Homi Bhaba Centre for Science Education (HBCSE) is another exemplary initiative undertaken to renew science (also mathematics) education. The centre made its beginning at a Municipal School of central Mumbai in 1974 as a unit of Tata Institute of Fundamental Research (TFIR) with a grant from the Sir Dorabjee Tata Trust. From 1981, the centre has been supported by the Department of Atomic Energy, Government of India. In 1992, it moved to its present independent campus located at Munkhurd, Mumbai. Promoting equity and excellence in science and mathematics education from primary to introductory levels and growth of scientific literacy in the country have been the broader goals of the HBCSE. Both pursuing academic research and exploration and analysis of science and mathematics education at the grassroot level form the bases for writing textbooks, teachers' books and developing laboratory material. Besides these engagements, the faculty members of the centre have been engaging in the reconstruction of science and mathematics textbooks at NCERT. At yet another level, the centre has become a nodal centre for the preparation of the teaching material and training the potential participants for in mathematics, physics, chemistry, biology and astronomy Olympiads and on some occasions has hosted International Olympiads in these subjects. National Initiative on Undergraduate Science (NIUS) at the centre nurtures talented science undergraduates to undertake advanced studies and research in sciences (Phondke et al. 2007). A few groups located at some of the Teacher training Colleges in Delhi, Mysore, Ajmer and elsewhere have worked in this field of study for some decades.

Some voluntary groups of teachers have responded to the need to create alternative pathways to renew education in the area of higher strata of science education. Establishment of Indian Physics Association (IPA) as a professional society, formed in 1970, is one such step. Since its inception, it has been working to promote the cause of physics research and education.

However, a group of tertiary physics teachers felt that IPA's mandate was to cater only to research activities and researchers at the universities and national institutions. Consequently, like minded physicists and physics teachers, in 1984, under the leadership of D. P. Khandelwal formed a new body--Indian Association of Physics Teachers (IAPT). This association resolved to look exclusively into the problems of physics education, particularly at the undergraduate level (Joshi 1997, 325). As a teachers' association, IAPT's resolution to contribute to physics teaching and learning fell in line with the recommendations of the National Commissions on Education (ME 1966, MHRD 1986) and the recommendations of Bhide Committee (Bhide et al. 1991) i. e. the teaching-learning process should be professionalized at the organisational level.

1.6 Indian Association of Physics Teachers (IAPT)

What are the epistemic problems that trouble physics educators in India? Joshi and Tillu (1989) while drawing on their experiences as physics teachers offer some insight into the problem. For example, what is it that results in an understanding of physics? Why do several students fail to develop a basic understanding of the framework of physics at the end of their undergraduate and postgraduate courses? They write:

> "Without much ado, one could point one's fingers at two major lacunae in the undergraduate education prevailing in Indian Universities which lead to malady. They are (i) lack of adequate training in scientific experimentation, laboratory work, handling of equipment, and (ii) lack of sufficient clarity in basic theoretical understanding as a result of an improper/inadequate training of science students in mathematical as well as in the logic of science. In our opinion, a fair amount of efforts have so far been made here as well as elsewhere to remove the first category of lacunae mentioned above.......We are not aware of any national programme which attempts to help students to shed their intrinsic fear of mathematics….In fact, as mentioned above, although we are subconsciously aware of it, no one even seems to have formally advocated the view in a concrete manner that a lack of appreciation of physics (or science) is a direct result of the lack of appreciation of the logical and mathematical structure underlining it....a large number of students often draw a blank because of these reasons…… Gaps in

> their understanding are often found to exist even in the elementary mathematical concepts, leave aside higher mathematics.[10]

Narlikar (1997) suggests that reforms in laboratory activities are not generally reflected in actual practice in classroom. Kumar and Nigavekar (1994) after examining the status of physics education in India have contended that though many efforts have been made in the improvement of education at the undergraduate level in physics in the past few decades but the picture is far from rosy. "In practice, however, theory courses are taught in a patchy and ad hoc manner, with no attempt to bring about the unity and beauty of the subject. Students are rarely encouraged to question critically and participate in classroom proceedings. Problem-solving without which physics courses are incomplete is virtually absent." (18).[11]

Though (HSTP) and (HBCSE), have endeavored to create a broader perspective on school science education, within a country of diverse needs the efforts of a few groups may not be sufficient in impacting upon the entire spectrum of science education. Keeping this in mind, the Planning Commission in 1991 appreciated the role of voluntary agencies working to renew school science education in India, and expressed the need to have similar agencies for college science education (Bhide et al. 1991, 31).[12] IAPT seems to fit well in the scheme as desired.

Since its inception IAPT claims to develop material and promote activities to further the growth of physics education. The National Standard Examination in Physics (NSEP) and National Graduate Physics Examination (NGPE) for plus two and graduate levels were launched to provide a bench mark for students to judge their conceptual understanding and problem solving ability.

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[10] A. W. Joshi and A. D. Tillu, "Importance of a quantitative approach in understanding concepts in physics," *Physics Education* April-June (1989): 39-40.

[11] Arvind Kumar and Arun S. Nigavekar, "Physics Education," in *Physics in India: A Status Report*, ed. Sudhanshu S. Jha (Indian National Science Academy, New Delhi: A Diamond Jubilee Publication, 1994), 18.

[12] V. G. Bhide et al., *Report of the Working Group to suggest ways and means to improve undergraduate course in science at Indian Universities/colleges* (New Delhi: Planning Commission), 31.

The IAPT members were asked to write cost effective and quality books for students, and brought out a volume entitled *Horizons of Physics*--a collection of expository articles on different areas of physics. Since its inception in 1984, the association not only runs a monthly journal called the *Bulletin of physics* but also has undertaken the publication of the journal of *Physics Education* and *Prayas--a Students' Journal of Physics* since 2001 and 2004, respectively. In order to cultivate the use of experiments in school and college teaching, Centre for Scientific Culture (CSC) at Midnapore and Anveshika (an alternative physics laboratory) at Kanpur were established by IAPT in collaboration with the host institutions. As a professional association, sharing new and useful ideas as well as relevant skills among teachers through seminars, workshops and orientation programs have also claimed to be the feature of IAPT's programs.[13] Indeed significant amount of work is accomplished by IAPT. Is it really a renewal of physics education or reproduction of tradition, need to be examined.

1.7 Rationale and Statement of the Problem

It is interesting to note that the physics education community constituted under the IAPT, outside the formal system of education, has been responding to the demand of renewal of physics education. Reflecting the concerns and efforts of the physics education community across the country, any insight into the nature of this problem and its subsequent resolution by IAPT is expected to influence physics education in India. In its portal, the association claims to have more than 5000 life members involving research workers, science administrators, science savvy enthusiasts and University, college as well as school teachers'.[14] As such it may form a 'community' of practice' (Wenger 1998). If seen as a 'community of practice', its members constitute an epistemological community seeking increased participation (based around certain visible structural styles and discourses) within their association. And hence, this interaction may stimulate a debate for understanding and

[13] See IAPT Portal at http://www.iapt.org.in/

[14] Data holds true for the year 2011. Refer to previous footnote.

resolving the problems of physics education in India.

Mapping the trajectory of the renewal of physics education IAPT has traversed entails answer to a number of questions. For instance, what was the historical context in which IAPT set on to renew physics education? How does IAPT relate to the contemporary developments in physics education? Has IAPT been moving along the physics education community worldwide or is it just reproducing the tradition? Understanding of this issue is critical for the possibility of the renewal of physics education in India.

Indeed, there are a host of challenges which the association may need to sort out to accomplish its objectives. For example, cognitively, major portion of the knowledge of the teachers (practitioner) lies tacit and pose problem to articulation (Schon 1995). Does IAPT members' training and experience equip them to articulate it well? Do they need to revisit the developments in other disciplines such as cognitive psychology and philosophy of science for developing deeper insights into the learning process in physics? Alternatively, do they have the adequate intellectual and material resources to articulate and explicate their tacit knowledge or conduct research to develop novel insight into the problem? Formally, what are the means and methods adopted by the association to conduct the debates, discourses, research, communication and dissemination of its work? More importantly to what extent these modes of knowledge production and dissemination have been effective in achieving the objectives set by it.

Generating the requisite amount of financial and infrastructural resources on sustained bases is supposed to be inevitable to support IAPT's work. How does the association earn resources to carry out its programmes? Do people and agencies funding its programmes impose conditions as a bargain? May be funding agencies come to support it only after a relevant piece of work is produced. Making a beginning under these conditions may be a testing proposition for the association. How has it been treading through these circumstances? Insight into this aspect is vital for understanding the very sustenance and progress of the association.

Though science and physics education has been a flourishing area of research for several decades, most of the studies conducted in this field deal with concept formation, problem solving, conceptual change, epistemology, laboratory activities etc. (Ganguly and Vashishtha 1991; McDermott and Redish 1999; Cumming 2011; Docktor and Mestre 2014). However, there is a virtual lack of studies tracing the role of professional societies in science and physics education. Commencing more than a decade ago teachers' associations called as 'professional learning communities' have evolved to cultivate a reflective practice among school science teachers in USA.[15] Almost all of these networks of teachers are formed to professionalize teachers' development on a larger scale. Some of the major theories on collaborative work like, Communities of Practice due to Lave and Wenger, or Activity System Theory of learning motivated by Vygotsky and Schon's writings on the Reflective-practitioner have informed the research efforts of these professional societies.

In the Indian context, Koul (2002) examined the discrepancies of the curriculum implemented by Hoshangabad Science Teaching Progrmme (HSTP) in the state of Madhya Pradesh. He concluded that the abstraction-dominated view of science among science teachers has been an impediment to locally relevant conceptualizations of science instruction. This conflict was further enhanced by the NCERT science curriculum implemented in adjoining schools. He suggested that teachers need to be given opportunities to engage themselves in the discourse on the issues of knowledge, power, nature of science and science teaching so that they can sustain themselves and see continuity amongst different curricula. Similarly, Sharma (2007) conducted an ethnographic study on grade seven students of a government

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[15] A review of literature on Professional Learning Communities was undertaken by Feger and Arruda (2008) and Stoll et al. (2006).

rural middle school in the state of Madhya Pradesh. After analyzing students' experiences and knowledge, he critiqued school science for not responding to the learning needs and resources of students in their rural settings. The study highlighted the adverse implications of the gap between learning needs and resources that students bring to the classroom, and the learning opportunities that school science offers them. In other words, science education programs need to be personally and socially responsible to the needs of underprivileged students in India. Prashad (2001) explored the status of physics education in India with special reference to the state of Andhra Pradesh. The study aimed to explore various internal and external factors shaping the curriculum, for example the language of instruction, history of physics, international developments in physics education and science popularization etc. He suggests the need for studies throwing light on the relationship between science, society and the physics as a discipline, in the curriculum.

Probably no study has been conducted so far to explore and understand the nature of work conducted by the physics teachers' association spanning over some decades. Thus a study in this regard acquires significance. Following IAPT's thrust to reconceptualise physics pedagogy and various activities and programmes developed to give it practical shape, the study is entitled:

"Indian Association of Physics Teachers: A Study of the Pedagogies, Programs and Policies of Physics Education"

1.8 Objectives and Research Questions

The following objective and research questions guided the study:

1. To trace historically the formation and evolution of the Indian Association of Physics Teachers:
    - What was the pedagogical and research context that motivated IAPT members to form an association for physics education?
    - Which were the various physics education networks and perspectives that led to the formation of IAPT?
    - How did the association expand in terms of its mandate and

concerns to represent the salient issues of physics education in the country?

2. To analyze the pedagogies, programmes and policies of Indian Association of Physics Teachers:
    - What were the different perspectives, problems and debates in physics education that animated the IAPT?
    - Which issues in physics education in India were considered significantly problematic by the IAPT?
    - In what ways did the experiences and expertise of IAPT members as teachers and researchers influence the programmes and policies of IAPT?
    - Which salient themes and programmes devised by IAPT were outcomes of Physics education research?
    - In which domain and how did IAPT benefit from its interactions with groups within and outside the country.
    - Over the years, how did the IAPT's perspective on physics education change?
    - Which programmes, policies, experimental protocols devised by the IAPT enter the physics education programmes at the school and collegiate levels?

1.9 Methodology

In its pursuit to renew physics education in India, IAPT since 1984, has traversed a significant time span. Seen in historical context, roots of this work traces back to the Education Commission (1966) and thereby enlarges the time span covered by the study. Essentially, the study maps the internal history of the association. Rather than some significant individuals, the activities bearing the stamp of the association as a whole are the concern of the study. The various perspectives emerged in science and physics education over several decades are drawn upon to interpret the pedagogic work conducted by the association.

1.9.1 Data Sources and Collection

The following written materials and activities on physics education comprise the primary data for the study:

[1] Literature on the theoretical developments in science and physics education was drawn from a number of journals and books related to the field.

[2] Literature on tertiary physics education, coming out of the programmes such as University Leadership Programmes (ULP), College Science Improvement Programmes (COSIP), reports on the review of physics education and books etc., was collected from a numbers of places and persons. These included the libraries of the UGC, Planning Commission, INSA, NCERT, Centre for the Development of Physics Education (CDPE)-University of Rajasthan etc.

The *Monthly Bulletin of the IAPT* serves as the vehicle for communicating the IAPTs' policies and activities among its members. The literature appearing in the journal is used to write IV, V and VI chapters. The data from the journal of *Physics Education*, *Horizon of physics--a* collection of review articles on physics; National Standard Examinations in Physics (NSEP) and National Graduate Examination in Physics (NGEP); Anveshika—an alternative physics laboratory at Saraswati Gyan Mandir (SGM) School at Kanpur; Centre for Scientific Culture (CSC) at Midnapore; Teachers' Orientation Programmes, seminars and workshops etc., forms the core of these chapters.

Copies of the *Bulletin of the IAPT* were gathered from the personal collections of R. N. Kapoor and Ved Ratna from Kanpur and New Delhi, respectively; journal of *Physics Education* was consulted at the NISCAIR Library New Delhi and Central Library of Pune University; the *Prayas-Students' Journal of Physics* was consulted at the Punjab University Chandigarh; *Horizon of Physics* were consulted at IGNOU, New Delhi and the Kanpur Centre of the IAPT; documents on

Anveshika (physics laboratory) and Centre for Scientific Culture (CSC) were obtained at Kanpur and Midnapore, respectively.

Secondary data such as articles, papers, books, editorial commentaries and a documentary etc directly or indirectly related to science and physics education were accessed from the available sources.

[3] Extensive unstructured interviews were conducted with some members of the IAPT.

1.9.2 Tools and Techniques

Bibliometrics is employed as a technique for analyzing the literature in the journal of *Physics Education*. The objective is to map the primary areas of concerns and the themes of pedagogical intervention. Centre of Scientific Culture (CSC) at Midnapore and Anveshika at Kanpur are projected as the prototype of the work initiated by the association and are significant in understanding the work of the association in regard to experiments. Observations were conducted to explore and record the data on the experiments designed and showcased at these sites. To further clarify the ideas and issues emerging from observations and literature analysed, interviews were conducted with them. Besides Midnapore and Kanpur, workshops organised at Delhi, Faridabad, Ambala, Meerut; IAPT Convention (at Jaipur, 2011; Kolkata, October, 2013 and Chandigarh, October, 2014); C. K. Majumdar Workshop on Physics at Kolkata (July, 2013), were visited to conduct observation and interviews.

1.10 Chapterisation

As evident, the first chapter identifies the research problem and locates it within the field of science and physics education. This is followed by a discussion of the rationale, objectives and methodology of the study. The second chapter reviews the development of science and physics education research, highlighting the conceptual milestones in science and physics pedagogy and the corresponding implications for curriculum and assessment at school and college levels. The conceptual framework is developed through the literature review that is then employed for understanding the nature of secondary and undergraduate physics pedagogy and the involvement of the Indian Association of Physics Teachers (IAPT).

The third chapter takes up the exploration of the problems and context surrounding the renewal of undergraduate physics education in the country. 1970 is identified as the crucial year for the work on physics education in India, eventually leading to the formation of IAPT in 1984. The time period reflecting the nature of the work Indian physics education community (beside IAPT) has engaged ends around the year 1995. The chapter discusses the issues, policies formulated and the plans implemented in undergraduate physics education in the country. The direct or indirect role played by the concerned institutions and individuals is explored. This sets the context for studying the formation and pedagogical programme of IAPT.

The fourth, chapter traces the formation of the association and formulation of its programmes coupled with a few of the institutional sites where these programmes were implemented. The individuals, institutional locations and motivations that shaped the mandate and priorities of the association are also the subject of concern. The establishment and sustenance of the physics laboratory at Centre for Scientific Culture (CSC)-Midnapore and Anveshika-Kanpur, and the subsequent attempts to popularise teaching physics through demonstrations and experiments is taken up in the fifth chapter. The chapter offers an interpretation of the observations recorded and interviews conducted during the field visits to these and a number of other relevant sites. The sixth chapter takes up the remaining programmes undertaken by the association. The chapter then concludes with a discussion of the activities and programmes pursued by the association. The chapter also takes up the exploration and interpretation of the nature of pedagogical engagement pursued by the association. Bibliometric analysis of the journal of physics education is taken up in seventh chapter. The analysis identifies the key-themes involving the concepts and priorities of physics education in India.

The classification of the publications into themes is discussed which become the variables of bibliometric analysis.

The final chapter attempts to synthesise the historical narrative with the themes and priorities identified in the programmes and activities pursued by the association. This is juxtaposed with the policy context of education that played an important role in shaping the evolution of the IAPT. Having the developments in physics education research in the foreground, the work is pedagogically interpreted. This is followed by the correlation of bibliometric analysis of the journal of physics education with the work of IAPT. Finally, a section of the chapter also discusses the impact of IAPTs efforts in intervening in physics education although historically the context is still too close.

Chapter 2

Perspectives on Science and Physics Education

The chapter aims to review emerging perspectives on science and physics education. While situating these developments within the field of physics education the review is used as a framework to understand the pedagogical measures undertaken by the Indian Association of Physics Teachers' (IAPT). The review opens with 'science education reforms' initiated during the 1960s setting the historical context for subsequent developments. The section then deals with the criticism of these reforms that paved the way for research in science education. The next section takes up the research concerned with the conflicting understanding of students' pre-instructional conceptions shaped by their day-today life experiences and the scientific ones they acquire during the course of instruction. Furthermore, the attempts to theorize 'conceptual change' deal with the shift from students' pre-scientific conceptions to scientific ones, and the empirical research conducted by science educators relating this issue, are dealt in this section. Problem-solving from expert vs novice perspective, another facet of the research on cognitive perpective, is dealt in third section. The criticism of the constructivist epistemology and introduction of nature of science component in science education research is dealt in the forth section. Finally, the emergence of physics education as a distinctive area of research and its impact on the professionalization of the field is discussed in fiveth section. By and large the review covers the discursive field of science education from elementary to school-college interface. Ignoring, the general and broader claims of research at these stages, the insights of school education are implicitly extended to undergraduate education.

2.1 Reforms in Science Education: 1950-60s

The foundation of science and physics education we are familiar with was laid down during 1950 and 60s. Science education has witnessed several progressive changes since then. The section explores the developments and successive reappraisal taking place in science education during the curricular reform period.

2.1.1 The Historical Context of Reforms in Science Education

The curricular reforms movement in the United States of America (USA) during 1950s and 1960s was landmark for the contemporary history of science education. Following an intensive period of research activity dictated by the demands of World War-II and its aftermath, a number of scientists turned to the study of science education. The National Science Foundation (NSF) funded science curriculum development projects involving scientists from different disciplines (Rudolph 2003; Cummings 2011). The launch of the Soviet Sputnik in 1957 triggered an anxiety across political spectrum in USA signaling that it had fallen behind in scientific and technological advancements. Among other factors, this was seen as major outcome of a deficient science and mathematics education. Criticism of science education programmes suggested that the American system of education was incapable of producing a generation of students who could rise up to the challenge. This generated processes to reform secondary and tertiary science education. Scientists from a number of top research universities such as Massachusetts Institute of Technology (MIT), University of California at Berkeley etc., led these initiatives (Little 1959; Cummings 2011). As a result, projects on writing textbooks, the production of related teaching material such as laboratory equipment, apparatus and workshops were designed to enhance the content knowledge of science teachers (Little 1959; Yager 1992, 2000; Park 2006; Cummings 2011).

At the introductory level, an innovative proposal from the Physical Science Curriculum Study (PSCS) in 1956 was the first outcome of this renewal. An improved version of this curriculum was prepared in 1960 by the Physical Science Study Committee (PSSC), and was followed by parallel developments in other disciplines such as the Biological Sciences Curriculum Study (BSCS), Chemical Education Materials Study (CHEM), and Earth Science Curriculum

Project (ESCP) etc. Concurrently, large-scale efforts designed to reformulate the undergraduate physics curriculum were undertaken at University of California at Berkeley, the California Institute of Technology (CIT), and the Massachusetts Institute of Technology (MIT) (DeBoer 1991; Park 2006; Pea and Collins 2008).[16]

2.1.2 Features of the reformed curriculum

Following scientists at the helm of affairs, curriculum developers gravitated towards an understanding of scientific inquiry deriving from how leading scientists thought and thus emerged the preferred pedagogical stance in these reforms (Finlay 1962/92; DeBoer, 1991). Replacing earlier thrust on the socio-scientific issues in progressivist era, different facets of the content of science were rigorously woven together. Logical reconstruction of theory constituting concepts, laws and principles of science, formed the bases for organising the curriculum. The mathematical formalism related physical phenomenon to the corresponding theory and provision was made for students to solve a large variety of problems following the assimilation of concepts.[17] Significant engagement with experiments and demonstrations in learning concepts and problem solving became hallmark of the curricula of this period (Hodson 1996; Schaim 2006; Duschl 2008).

Joining hands with scientists, science educators also played their role in shaping the science curricula. Joseph Schwab, a prominent science educator of the day, headed the Biological Sciences Curriculum Study (BSCS). His analysis of the nature of science suggests that scientific knowledge has both a substantive and syntactic structure. The substantive structure refers to the way in which facts, concepts, principles and theories of the discipline are organised based on certain principles. The syntactic structure of a discipline is the set of procedures for establishing the validity of the elements of the substantive structure. Like grammar, syntax provides the rules to determine

[16] Surprisingly, there is a virtual lack of literature on the debates, criticisms and developments of tertiary science and physics education.

[17] The form of curricular organization continues even today.

the warrant for competing claims (Shulman 1986). In what he termed as ‘enquiry into inquiry’ Schwab contended that science is taught as rhetoric of conclusion or a finished product. As such it creates an image of science which becomes, empirically and literally, the generation of truth or dogma. He proposed that rather than the rhetoric of conclusions what students need to be taught is the way scientific community actually does science (i. e., revisionary, fluid and changing in character). Teachers need to lead students to critically inquire into the literature scientists have produced. This requires inculcating the ability among students to debate and discuss how problems are formulated, methodology is pursued and data are generated in science to arrive at valid conclusions on their own (Robinson 1969; Rudolph 2003; Trumper 2003). Laboratory experiences were placed at the centre stage of this scheme. Experiments were designed to lead and not follow the teaching of theory. Rather than being structured and guided by the teachers and laboratory manual, teachers need to create conditions to help students conduct some exemplary inquiries by asking them to draw upon their own intelligence and judgment while pursuing the activity (Robinson 1969).

Arguing on similar lines, Rutherford (1964) argued that both content and concepts needed to be understood in the context of their discovery. This meant that science teachers be adequately acquainted with the developments in the history and philosophy of science. Gerald Holton initiated the ‘Harvard Project Physics’--a repertoire of brief historical case studies and proposed a historical method for physics teaching (Holton 1967, 2003). At the elementary level, drawing on Jean Piaget’s pedagogical theories, Robert Karplus (1974) working with the project ‘Science Improvement study’ (SIS) formulated a three stage learning cycle via exploration, understanding and application of concepts for elementary students. The cycle aimed at experiential knowledge leading to the discovery or understanding of scientific concepts.

Similar curriculum initiatives were undertaken in United Kingdom (UK) during the 1970s. What was termed as ‘discovery approach’ in USA was described as a 'process approach' in UK (Hodson 1993, 1996; Millar 2004). In giving prominence to the processes of acquisition or construction of scientific knowledge, this approach promoted the view that science entails a rigorous and algorithmic procedure that is universally applicable. The long-standing belief from the 'progressive era' continued to influence the curriculum.[18] Children were seen motivated enough to learn directly from unstructured play - unlike in inquiry activity. The belief was reinforced by Jean Piaget's ideas that over the years the unstructured and self-directed activities of children, while passing through a series of intermediate developments, lead to independent and sophisticated formal reasoning like adults. This gave rise to the notion that every time new knowledge is learned, it has to be rediscovered. In a way, it was the theoretical justification for the revival of the 'heuristic approach' first developed by Henry Armstrong in the early twentieth century (Millar 2004).

2.1.3 Critique of the Reform Movement

The reformed curricula implemented through the decades of 1960s did not stand up to expectations. Its impact dwindled around the mid 1970s (Driver and Easley 1978). While conducting a post implementation analysis of the reformed curricula, many science educators (for example, Driver and Easley [1978]; Hodson [1985]; Millar and Driver [1987] etc) sensed something problematic with the nature of these curricula. The concurrent shift in the conception of science and cognitive psychology during this period reinforced the reappraisal of the science curriculum reforms. The following sections shed light upon the subject.

[18] Progressivism is an umbrella term used for the reforms undertaken in a wide range of social, economic, and political and educational spheres during late nineteenth and first half of the twentieth century. In the arena of education, progressivism suggested that science was an instrument for social change. John Dewey's ideas were most influential in shaping this philosophy. In the science curriculum, employing the scientific method for investigating social issues and problems (community life around the learner) was at the centre stage in the curriculum. The inquiries pursued by the students were supposed to result in discoveries like scientist do, albeit in their limited context (deBoer 1991)

2.1.3.1 Discovery and Process Approaches

Whether it was the 'discovery learning' or 'process approach', the pedagogic approach proposed during the curricular reform of the 1960s sought to create conditions conducive for inquiry and expected students to form concepts themselves (Hodson 1988, 1996).[19] The reappraisal commenced with the idea that while the understanding of science had progressed, the epistemology of science education enshrined in science education reforms was stuck in the inductive-empiricist view of science (Kreitler and Kreitler 1974; Millar 2004). The premise underlying reformed curricula was that scientists look at the world with no a priori ideas and that they observe, collect and record data objectively. They then infer relationships and generalizations from the facts so collected (Hodson 1985, 1996; Yager 1992; Duschl 2008). When looking through the lens of 'rationale of the scientist', not only scientists but science educators could not discern the distinction between the epistemological and pedagogic basis for science teaching. Curriculum innovators acted with the belief that the way science is practiced is also the best way to teach and learn science. In other words, if experimentation is central to the epistemology of science, it should also be central to the epistemology of the science curriculum. The dilemma was to structure the theory of teaching or to anchor a theory of education entirely upon a philosophy of science (Hodson 1985, 1992, 1996; Duschl 2008).

Results revealed that students could not discover something that they were conceptually unprepared for. In attempting to discover for themselves, they did not know where to look, how to look, or how to recognize a concept when they found one. Initially, teachers pretended that class room activity was an open-ended enquiry and deliberately suppressed the needed guidance to the students. What was purported to be student-driven inquiry ended in a subtle but very powerful form of teacher's direction and control. The teachers

[19] The ideas of Jerome Bruner (1961, 1966) and Joseph Schwab (1962, 1966) were influential in discovery and process approaches at the elementary and secondary levels, respectively.

guided the class discussion of the 'experiment' to be carried out (Hodson 1996; Millar 2004). Thus, many teachers responded to the pedagogical problems of 'discovery learning' by engaging in what came to be known as 'directed' or 'guided' discovery (Hodson 1996).

Psychologically, educators taking up the reforms saw student as a miniature version of the scientist. However, in reality, students neither possess the theoretical sophistication nor the wealth of experience of the scientist. Thus the way students go about inquiry cannot be equated with the investigative methods of the scientist. Before being able to discover science for themselves, they must acquire the accumulated wealth of scientific knowledge first (Kirschner 1992; Hodson 1996; Kirschner, Sweller and Clark 2006). They cannot learn science by pretending to be junior scientists. At most they could investigate relationships between concepts through the discovery approach but this cannot become a central approach leading with certainty to new concepts (Hodson 1996).

2.1.3.2 Expository Method

Requirement to engage with concrete experiences in learning by discovery distracted students from central conceptual issues, thereby obstructing rather than encouraging conceptual development. Moreover, while overemphasizing the idea of inductive science, it left little space for the transmission of pre-organized content (Kreitler and Kreitler 1974). This invited a reconsideration of verbal transmission or reception learning proposed by David Ausubel in 1968. Ausubel grounds his defense of teaching by verbal transmission on, among other arguments, the inability of most students for discovering all that they need to know. Thus he proposed to expose students directly to well-formed concepts and expected them to grasp or comprehend them. The proposal was termed as the 'expository method'. The method consisted of advanced organizers (putting the central concepts as headings), progressive differentiation from previously familiar knowledge, correlative subsumption of ideas and reconciliation among contradictory ideas leading to the integration of new ideas with previous concepts (Driscoll 1994, 111-137). Successful exposition through these organising principles relies largely on the reservoir of previous experiences stored in the learner's mind instead of providing opportunities for acquiring new direct experiences in the learning situation itself. According to Ausubel (1968) meaningful learning can result from discovery or verbal leaning methods provided ideas are interlinked effectively. The lack of inter-linkages among ideas results in 'rote learning'. This became hallmark of the expository method. This enhanced the teacher's role in connecting constituents of the conceptual structure of science and thereby facilitating meaningful learning (Trumper 2003).

Following Ausubel's proposal concerning the comprehensive integration of concepts, educators and psychologists of most varied disciplines and schools readily agreed to test the idea (Kreitler and Kreitler 1974). Numerous studies showed that the teaching of concepts promoted learning through the organisation of curricular material into relatively big units, by highlighting the relationship between the material learned at more elementary as well as advanced levels, by delaying forgetting, and by stimulating the maximum degree of transfer of a conceptual scaffolding (Novak and Musonda 1991). It became clear that there is no knowledge without theory and facts are meaningless when detached from concepts (Hodson 1996).

Notwithstanding a fair degree of success, the expository approach also proved inadequate as a central instructional approach. The approach did not reconcile procedural and conceptual knowledge. Scientific concepts turned out to be external to the experiences of the students receiving them and were often labeled too abstract. If not complemented by concrete experiential basis, concepts could become empty verbiage, and result in unfounded generalizations (Shulman 1986; Hodson 1985, 1996). Moreover, negative attitudes of students towards science learning, revealed the neglect of affective components (Posner et al. 1982; Hodson 1985; Driver et al. 1994;

Cakir 2008). Eventually, the realization dawned upon science educators that effective learning of science by students would require the judicious mix of 'hands on' and 'minds on' approaches (Hodson 1996).

2.1.3.3 Role of Experiment

The criticism of discovery and process approaches during the 1960-70s had necessitated the reconceptualisation of the role of experiment in science education. Now it is well established that the differences in the role of experiment in science and science education corresponds to the differences of contexts. According to Hodson (1996), while experiment in science is primarily for the development of theory; in educational settings, it has a range of pedagogic functions. In its popular role in the transmission of knowledge, experiment helps to demonstrate deduction of concepts from theory. Thus, rather than turning concrete to abstract, as is the case with discovery or process approach, the function of experiment is to change abstract concepts and theory into concrete reality. In other words, when instruction has done with concept formation or theory development, the experiment fulfills the illustrative function or concretisation required by the verbal expository method of teaching (Kreitler and Kreitler 1974; Hodson 1992, 1996).

In regard to problem solving, as Kreitler and Kreitler (1974) put it, experiments can also play a useful role if the objective is to evoke conceptual curiosity and in rendering a wide spectrum of conceptual background worthwhile. However, these two conditions depend more on the exposition of content during lectures and discussion than merely performing experiments. The performance of an experiment plays a restrictive role at the stage of posing a problem, analyzing a problem, raising alternatives for its solutions, and evaluating these alternatives. Anchorage in the concrete inhibits the processes underlying problem solving, and their adequate formulation. Additionally, it may promote functional fixity and restrict the fluency of ideas in devising alternative solutions, that is, it may inhibit those processes which lie at the core of spontaneous elaboration and creativity. It is at the crucial stages of testing solutions where experiment becomes the most efficient tool. Since practically only a small part of a solution may be tested empirically in science instruction, the principle acquires significance (Kreitler and Kreitler 1974; Millar 2004).

Though important in illustrating the substantive structure of science (concept formation in particular), the experiment is not the only one means to do so.[20] A wide range of other means such as oral or written exposition of concepts, thought experiments, computer simulations and so forth are required to deepen concept formation (Hodson 1992). What binds these cognitive skills together is the goal of conveying the substantive structure of a knowledge domain. Serving this goal, these techniques, together with experiments and classroom activities (lecture, theory lessons, textbooks), it is argued, are supportive of each other (Hodson 1996).

While making a binding arguments on the role of experiment, Hodson (1992) asserts that science teaching should be concerned with introducing students to a body of knowledge and with familiarizing them with the way a problem-solving scientist works. The former, the substantive structure of science, is a vehicle in aiding the understanding and deriving enjoyment from science. The latter, the syntactical structure of science is a vehicle in helping students develop certain habits or skills and subsequent application.[21] Though experiments are more suited for conveying the syntactical structure of science, in conjunction with other techniques, it can foster bridges between substantive and syntactical structures of science. Apparently the sole use of experiment for concept formation does not prove to be efficient and economical. On the other hand, experiments must involve students in the use of logical procedures and strategies in demonstrating the implications of scientific theories and laws; stimulating the ability to pose good questions,

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[20] 'Substantive structure' refers to the facts, rules, principles, concepts etc. The term due to Joseph Schwab and is already explained in an earlier section.

[21] 'Syntactical structure' is also a Schwabian term meaning a set or structure of the implicit or explicit rules for establishing the validity of scientific claims by the practitioners.

recognising regularities, symmetries, diversities, and commonalities among observations. For experiments to attain its curricular objectives there must be opportunities for using alternative procedures for devising related experiments and choosing the appropriate means for recording and interpreting observations. The assimilation of concepts is enhanced when a series of experiments are integrally related to these roles at a particular level of physics instruction (Hodson 1993).

Apparently, to perform these roles, experiment must function as an intellectual rather than a manipulatory skill; to aid students impose intellectual order on data**.** For example, the ability to recognise problems, understand experimental methods, organise and interpret data, understand the relation of facts to the solution of problems, plan experiments to test hypotheses and make generalisations and assumptions, comprise intellectual skills (Hodson 1992). Notwithstanding a spectrum of arguments on the plausible roles of experiment, conceptualisation of science encapsulated in hypothetical thinking, is the overriding goal of instruction. To enrich instructional process, experiment has to fill into the requisite gaps as per the role accorded to it. After providing a sufficient experiential base students are gradually led to free themselves from subservience of the concrete and from the dominance of present stimuli (Trumper 2003; Millar 2004).

2.2 Learning Science: Students' Perspective

Reform in science education became predominantly discipline-centric in nature. 'Think like scientist' became a metaphor for learning that relegated students' nature into the background. Pointing out to the direction in which science education was unfolding after curriculum reform period during 1950-60s, Carey (2000) writes:

> All the good teachers have always realized that one must start where the student is. During 1960s, it was defined in terms of what the student lacked, and this was the lack of science content knowledge, combined with age related limitations in general cognitive capacities (e.g., the elementary school child is a concrete thinker not capable of abstract reasoning). Now

> we understand that the main barrier to learning the curricular materials we so painstakingly developed is not what the student lacks, but what the student has, namely, alternative conceptual frameworks for understanding the phenomena covered by the theories we are trying to teach. Often these conceptual frameworks work well for children, so we face a problem of trying to change theories and concepts.[22]

Gaining empirical insight into the processes at play as the learners' knowledge in science evolves became all the more crucial Carey asserts. The section takes up the developments in this regard.

2.2.1 Nature of Pre-instructional Conceptions

The validity of two theoretical ideas from psychology was brought to test. The first was Ausubel's (1968) idea that the most important single factor influencing learning is what the learner already knows.[23] And the second was Piaget's (1970) idea of the interplay of the processes of assimilation and accommodation in learning and his clinical interview method investigating learners' conceptions about scientific phenomena. Equipped with these ideas science educators set to conduct inquiries into students' pre-instructional conceptions and identify impediments to students' acquisition of science as posited in the reformed curricula (Driver and Easley 1978; Niaz et al. 2003).

Instead of dividing students' responses into correct and incorrect categories, researchers gave importance to what students were telling and actually doing on the tasks in different domains of instruction. Surprisingly, while uncovering the underlying structure and meaning in students' responses, researchers found that students' had ideas competing with the ones presented in the instructional setting (Villani 1992; Smith III, diSessa, and Roschelle 1993). The observed differences between students' and scientific ideas created the need to characterize these differences and approaches.[24]

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[22] Susan Carey, "Science Education as Conceptual Change," *Journal of Applied Developmental Psychology* 21, no. 1 (2000): 13-14.

[23] Having been introduced in the 'Expository Method', idea was set to be tested in research context.

[24] Each term has its adherents offering particular justification, but, as yet there is no universally accepted term (Ambimbola 1988). Smith III, diSessa and Roschelle (1993, 119) offer a typology of terminology researchers use to discuss the matter. Namely, these are 'preconceptions' (Clement 1982; Glaser and Bassok 1989; Wiser 1989), 'alternative

'Misconception' was the common denominator designated for students' conceptions that produce a systematic pattern of error. From a handful of investigations in a small number of science domains in the mid of 1970s, research expanded to nearly every domain of science by the mid-1980s.[25] The outcomes of the investigations were delineated in terms of the three major features. Misconceptions have their origin in students' encounters in daily life. Due to prolonged exposure they are deeply entrenched compounded by explanatory power they have about many physical phenomena and their encounter with the environment. As a result they become robust in themselves and offer resistance when scientific conceptions are offered to replace them (diSessa 2006; Ozdemir and Clark 2007).

The salience of these ideas has been found consistently across diverse samples and conventional instructions at school and university levels (Singer, Nielsen and Schweingruber 2012). diSessa (2006) offers an illustration of the tenacity of students' conception. According to him:

> Concept of force provides an example of conceptual change in physics. As per the scientific account of simple event of tossing a ball into the air, physicist would say there is only one force, that is, gravity operating on the ball from the moment it left the hand. Gravity acts on the speed of the ball, diminishing it until the object reaches zero speed at the peak of the toss. Then, gravity continues acting, pulling the ball downward, so the ball accelerates downwards until it is caught at hand. Before the conceptual change research begins, instructor might have attributed to the abstractness of physics or to its complexity. Instructional interventions might include simplifying exposition or repeating basis instruction. These reactions to students' difficulties assume acquisition model of learning. In contrast, listening closely to students explanations yielded a stunning discovery. Students do not exhibit lack of descriptive or explanatory capability, but they have radically different things to say than experts. A

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conceptions' (Hewson and Hewson 1984), 'naive beliefs' (McCloskey, Caramazza, and Green 1980), 'alternative belief' (Wiser 1989), 'alternative frameworks' (Driver 1983; Driver and Easley 1978), 'naive theories' (McCloskey 1983; Resnick 1983), and more popular one the 'misconception'. Though deviation from expert or teachers is the common thread across them, the variation among them reflected differences in how researchers have characterized the cognitive features of students 'ideas and their relation to science concepts.

[25] For instance see the review: H. Pfundt and R. Duit, *Bibliography: Students' alternative frameworks and science education*, 4th ed. (Kiel: IPN, 1994).

> typical novice explanation: Your hand imparts a force that drives the ball upward against the gravity. The upward force gradually dies away until it balances gravity at the peak. Then, gravity takes over and pulls the ball downward. Student seems to have prior concept of force but it is different from expert. Instruction must deal with these ideas and change them: enter the era of conceptual change. Early in conceptual change research, most people assume that students' ideas were coherent and integrated. Under such assumption, one has little choice but to argue students out of their prior ideas, and convince them to accept the ideas of physicist.[26]

As novices unconsciously develop coherent structures through collections of daily experiences, their theories are not available for hypotheses testing in a manner similar to scientist's theories. However, these do constrain future learning even though they enable the learner to make predictions across conceptual domains. Eventually, it was acknowledged that students' conceptions have to be taken into account before imparting scientific conceptions (Driver and Easley 1978; Hewson 1981; Vosniadou 1994; diSessa 2006)

2.2.2 Conceptual Change Model and Empirical Evidence

Having probed the nature of students' pre-scientific conceptions, science educators now articulated a theoretical model aiming to explain the substantive process by which students' conceptions change. Posner et al (1982), informed by Thomas Kuhn's (1962) notion of paradigm shift in science and Jean Piaget's (1970) notion of accommodation in genetic epistemology, proposed a theory of conceptual change for science students. According to this theory the current conception of students is functional and solves problems within the existing conceptual schema, and thus they do not feel the need to revise this conception. Moreover, when unable to solve some problems, the learner may make some moderate changes to his or her schema. In such cases, assimilation occurs without any need for accommodation. The following 'cognitive conditions' facilitate revisions in conceptions:

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[26] Andrea A. diSessa, "A History of Conceptual Change Research: Threads and Fault Lines," In *Cambridge Handbook of the Learning Sciences,* ed. Sawyer K. (Cambridge, UK: Cambridge University Press, 2006), 266.

1) The change in the current conceptions is initiated with the accumulation of unresolved problems or anomalies leading to cognitive conflict.
2) New conceptions enable the interpretation of experiences with novel analogies and metaphors etc.
3) The new conception should be compatible with the conceptions or knowledge structure coming from other fields.[27]

Borrowing from Stephen Toulmin (1972), Posner et al. (1982) embedded their explanation of conceptual change within a 'conceptual ecology' perspective. The 'conceptual ecology' of students is the symbiotic relationship between their conceptions and the complex constituted by their ontological and epistemological beliefs. Furthermore, beliefs about commonplace science, competing conceptions, knowledge in other fields and their relation with science comprise the complex of 'conceptual ecology'. Metaphysical beliefs are beliefs about the ultimate nature of the universe--for example, the belief in absolute space and time, the extent of orderliness, symmetry or homogeneity etc. These beliefs are immune from direct refutation. They also shape epistemological views which in turn activate the acceptance or rejection of particular explanations. Analogies and metaphors provide organisational coherence to the conceptions or knowledge characterised as elegance, economy and parsimony and not being ad-hoc. These characteristics come with epistemological commitments regarding what counts as a successful explanation in the field. Lastly, anomalies are the new observations not explained by the existing conception and demand a change in them.[28]

Apparently, concepts are not independent from the cognitive elements or schemas within a students' conceptual ecology and some concepts are attached to others that generate thoughts and perceptions. Because of this web like relationship among concepts, a revision in one requires revision of others. It is precisely here that teachers do not seem to have clarity and

[27] George I. Posner et al., "Accommodation of a Scientific Conception: Toward a Theory of Conceptual Change," *Science Education* 66 (1982): 211-214.
[28] Ibid., 214-215.

therefore could not design instruction for conceptual change. While attempting to effect conceptual change generally they do not take into account the combinatorial complexity inherent in the conceptual ecology. As a result resistance or failure in conceptual change is encountered.

Over the years, cognitive conditions and conceptual ecology have provided an overarching framework for understanding conceptual change in students. With further empirical evidence the role of affective (for example motivation) and psycho-motor elements was incorporated into the framework of 'conceptual change' by Strike and Posner in 1992. It was recognized that interests, values and efficiency in manual skills play a role in conceptual change.[29] As an instructional model it was supposed to enable students abandon their pre or extra instructional conceptions and accept scientifically appropriate alternatives which they could otherwise not dismiss, ignore or reinterpret. However, on account of being highly sophisticated, testing the efficacy of all the elements of this model in a single trial proved to be untenable. Empirically, the conceptual-ecology perspective of this model offers explanatory possibilities. Virtually the role of all the elements (anomalous data, analogy, ontological and epistemological beliefs or expectation) in shaping students' conceptions has been tested (Özdemir and Clark 2007; Docktor and Mestre 2014).

The exemplary studies examining these aspects of conceptual change are mentioned here. The ontological attribution plays a vital role is conceptual understanding. Concepts are attributed to have two distinct ontological categories—materialistic and processual ones. The conceptual problem in novices results due to the misclassification or misplacement of ontological

[29] Strike, Kenieth A. and George I. Posner, "A Revisionist Theory of Conceptual Change', In *Philosophy of Science, Cognitive Science, and Educational Theory and Practice*, eds. Richard Duschl and R. Hamilton (New York: State University of New York, Albany, 1992), 147–176.
Also refer to Paul R. Pintrich, Ronald W. Marx, and Robert A. Boyle, "Beyond Cold Conceptual Change: The Role of Motivational Beliefs and Classroom Contextual Factors in the Process of Conceptual Change," *Review of Educational Research* 63¸no. 2 (1993): 167-199.

categories. Students as novices have the tendency to classify a concept as material substance. On the other hand experts are successful because they can connect concepts with processual or emergent ontological categories. Novices experience a significant barrier in making shift from material to processual ontological categories. The concepts of force, light, heat, electricity are labelled as notoriously difficult for the students in this regard (For example Chi, Slotta and de Leeuw 1994; Slotta and Chi 2006). Gupta, Hammer and Redish (2010) contest this view, arguing that expert and novice reasoning often and productively traverses ontological categories. Rather than being distinct, stable and constraining, ontological categories are flexible in nature. To promote one static ontological attribution in physics instruction could undermine novices' access to productive cognitive resources they bring to their studies and inhibit their transition to the dynamic ontological flexibility required of experts. In other words mixed ontologies i. e. both materialistic and emergent (processual) are fundamental part of the thinking of professional scientists and are common and productive in both everyday life and instructional setting.

Countering the criticism labelled by Gupta et al (2010), Slotta (2011), argue that Slotta and Chi (2006) too have attributed dual ontological categories and traversing between them. There may also be some topics in physics—particularly in modern physics—that defy any single ontological attribution. Light, for example, have strong ontological duality. Even particles—the seemingly epitome of a substance-based ontology—can sometimes appear as emergent processes (i. e., as in Brown Young's double slit experiment). Similarly, Duit (1991) has recorded the role of analogies and metaphors in the learning of science.

Epistemological beliefs can affect how students approach learning and how they benefit from instruction (for example, Carey and Smith 1993; Hammer 1994; Roth and Roychoudhury 1994; Redish, Steinberg and Saul 1998). Hammer argued that emphasis on parting the gap between concepts and problems solving of novices and experts is not sufficient. Part of the problem lies with the epistemological beliefs students has (Hammer 1994). The framework of epistemological beliefs consists of three dimensions. Structure of knowledge, describes a range of epistemological beliefs having pieces and coherence of knowledge at opposite ends. Knowledge as pieces describes knowledge as a collection of isolated pieces of information, formulas and facts. Coherence of knowledge at the other end is a belief that physics knowledge constitutes a coherent system and making sense of it is vital. Conceptual content is the second dimension of epistemological belief system. Understanding of the conceptual content underlying mathematical formalism on the one end is attributed to have essence and formalism, the language to express or apply it. On the other end, physics knowledge is thought to consist of facts, formulas, and procedures. Students having belief at this end, prefers to solve problems with symbolic means by identifying and manipulating formulas. Thirdly, learning physics is about becoming autonomous in developing understanding of physics at the one end and receiving it from the teacher or the text (as authority) at the other.[30]

Rather than articulate and stable, epistemological beliefs of the students are tacit in character. More successful students could be characterized by coherence, conceptual content and independence. Students standing on the other side of the spectrum though may repeat the standards epistemological beliefs; they do not generally correspond to what they really believe. Hence explicating and aligning their beliefs with the major objectives of conceptual understanding and problem solving should be the instructional objective (Hammer 1995).[31]

Even if the process of conceptual change implies the revision and restructuring of an entire network of beliefs and presuppositions, Posner et

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[30] David Hammer, "Epistemological beliefs in introductory physics," *Cognition and Instruction 12* (1994): 151–183.

[31] David Hammer, "Epistemological considerations in teaching introductory physics," *Science Education* 79, no. 4 (1995): 393-413.

al's model (prior to its being tested) favored the revolutionary i. e., instantaneous change. Subsequently when empirical results were offered by the aforementioned studies, it signaled to be an evolutionary process. Carey (1999) was direct in proposing gradual transformation of students' conceptions. Also Carey's findings contradict the Piaget's proposition that after having passed through the hypothesis formation stage in their cognitive development, the acquired conceptions in a particular domain naturally leads to the acquisition of similar conceptions in other domains. According to her, experiences specific to a particular domain are required to make transition in conceptions.[32]

2.2.3 Elemental Perspective of Conceptual Change

Considered as the primary mechanism for conceptual change, 'cognitive conflict' has been the most frequently tried one. It was presumed that once students are made aware of the conflict between their pre-instructional and scientific conceptions, they would be ready for acquiring the latter. However, contrary to expectation has obtained mixed outcomes (diSessa 1993, 2006; Özdemir and Clark 2007; Docktor and Mestre 2014). While reviewing the research, Chinn and Brewer (1993) concluded that similar to scientists, students respond to anomalous data in seven different ways: ignoring, rejecting, excluding, putting it in abeyance, reinterpreting, making peripheral theory change, or final theory change. This led scholars to question the efficacy of cognitive conflict as the mechanism for conceptual change (Smith III, diSessa and Roschelle 1993; Linder 1993; diSessa 1993, 2006; Niaz et al. 2003). It was contended that cognitive conflict sees students' conceptions as erroneous or as misconceptions and as such it is pitted against or in confrontation with scientific conceptions. Moreover, discarding students' prior conceptions in favor of scientific ones does not leave space for in-depth calibration and making them the resource for transiting to scientific

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[32] Susan Carey, "Sources of conceptual change," in *Conceptual development: Piaget's legacy,* ed. E. K. Scholnick, K. Nelson, and P. Miller (Mahwah, NJ: Lawrence Erlbaum Associates, 1999), 293-326.

conceptions (diSessa 1993). Consequently, a number of researchers became interested in understanding students' conceptions in terms of naive knowledge structures consisting of multiple quasi-independent conceptual elements such as anchoring conceptions, phenomenological primitives and mental models at various stages of development and sophistication.[33]

Not every conceptions students hold is a misconception. For example, 'springiness' is the intuitive knowledge structures of novices' that happens to be in rough agreement with the scientific knowledge. In order to resolve the conceptual difficulty that a table exerts a normal force on the book resting on it (visibly not springy), analogy is established with hand placed on spring (hand-on-the-spring). To make the case more apparent, a book resting on a flexible board (less springy) is placed in between. Analogy is established as intermediate case forms a bridge by sharing common features with the objects placed at its opposite ends (Clement, Brown, and Zietsman 1989). Likewise, conceptual difficulty relating to frictional forces and Newton's third law of motion are resolved by forming a structural chain between anchoring, bridging and target conceptions. It is implied that more and more such analogies need to be established by the science educators (Clement 1993).

diSessa proposes that the knowledge structures of novices primarily consists of unstructured collections of phenomenological primes or p-primes. P-primes are developed through interactions with the physical world like pushing, pulling, throwing and holding. The learner merely assumes that something happens because that is the way things are (diSessa 1993, 112). These implicit presuppositions influence learners' reasoning in interpreting the world. In common with other strands, these p-primes are generated from the learners' experiences, observations, and abstractions of day-today life phenomena. Yet, p-primes are not produced or activated under highly organised systems like theories. At most p-primes are loosely connected to

[33] Anchoring conceptions was coined by Clement, Brown, and Zeitsman (1989); phenomenological primitives by diSessa (1993); and mental models by Vosniadou and Brewer (1994).

larger conceptual networks. It is through cuing as a mechanism p-primes are recognised and activated in a particular context. Thus perspective on p-primes takes students' conceptions as a primary resource for progressive reconstruction of scientific concepts. For instance, p-primes such as force as mover, dying away and spontaneous resistance describe events in the physical world; and despite intermediate difficulties their gradual re-crafting into more complex and stable scientific conceptions can eventually be achieved by cuing them in appropriate contexts (diSessa 1993, 123-124).[34]

As facilitator of conceptual change, teachers are expected to make students aware of the central pieces of their knowledge and facilitate their use in appropriate contexts (diSessa 2006). In terms of specific instructional strategies, restructuring, editing, and organizing the pieces of knowledge elements is required rather than making discrete changes in one conception after another (Özdemir and Clark 2007).

P-prims are obviously sub-conceptual, sub-theoretical, or sub-model-like. They are too small to constitute any of these macro structures, and the most

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[34] Following examples of p-primes given by Andrea A. diSessa, "Why "Conceptual Ecology" is Good Idea," in *Reconsidering Conceptual Change. Issues in Theory and Practice,* ed. M. Limon and L. Mason (Netherlands: Kluwer Academic Publishers, 2002), 40.
"(1) Ohm's p-prime: A tri-partite element with an impetus (effort), a resistance, and a result: Effort works through a resistance to achieve a result. Ohm's p-prime entails the following expectations: More effort begets more result; more resistance begets less result; and so on.
(2)Force as a Mover: An abstraction of a push or toss: Things go in the direction you push them.
(3)Dying away: Induced motion just dies away, like the sound of a struck bell
(4)Dynamic balance: Sometimes, efforts or impetuses conflict and (accidentally) cancel out, like two people of equal strength pushing against each other.
(5)Overcoming: Is a situation of conflicting efforts, where one wanes or increases, yields a characteristic switch from the outcome associated with one effort to the outcome associated with the other. For example, a person pushing against another increases his effort and moves the other back.
(6)Return to equilibrium: Systems that are "out of balance" tend to return to "equilibrium.'" For example, a balance' scale pushed out of level returns to level. Water levels itself in a pan.
(7)Generalized springiness: In "out of balance" systems, the displacement from equilibrium is proportional to the amount of perturbation that is applied.
(8)Contact conveys motion: A typically small or light object in contact with another typically large or heavy one and moving with it. For example, a box in a wagon moves with the wagon.

plausible developmental path between naive p-prims and any of these structures is one of the parts of the emergent complex knowledge system. In other words, p-prime does not offer a complete description of the knowledge system novices have. What are the other elements, beside p-primes, constituting complex knowledge system? Analogous to the 'conceptual ecology' due to Posner et al (1982), diSessa proposes 'coordination class' constituting the complex knowledge systems of both novices and experts. Coordination class is refinement of the idea of concept--scientific or pre-scientific. Theories are likely to be even larger conceptual structures, encompassing several related concepts (or coordination classes). For example, force, mass, and acceleration may each constitute coordination classes and Newton's theory might be abbreviated in a particular relation among these coordination classes (diSessa 2002, 53).

In contrast to p-primes, coordination-classes are few and large. These are complexly articulated subsystems, for example by the process of readout strategies and forming causal net to integrate many small elements like p-primes emerging over a period of time. It enfolds articulate components like $F = ma$ or one has to have force to sustain motion and determines a certain class of a function across many contexts.[35] Coordinated actions across contexts entail appropriate span, integration and alignment. As such it possibly accounts for major developmental accomplishments such as determining time duration or "object permanence". Eventually it defines a model of the system constituting expert concepts and supplies inference from observations to theoretical entities (diSessa 2002, 53).

Vosniadou (1994) proposes 'framework theory' for naïve physics. According to her, students do not have stable misconceptions at the first place. They do not have a collection of unstructured knowledge elements either. Rather it is a complex knowledge structure consisting of perceptual experiences, information, beliefs, presupposition and mental representations. The

[35] '*F*' stands for force, 'm' for mass and 'a' for acceleration.

organisation of these elements into a coherent framework enables them to explain the physical phenomenon they encounter. The formation of their knowledge has its origin in the sensory and perceptual experiences with the physical world shaped by the culture and language students are embedded in. Naïve framework theory contrasts with the scientific knowledge in abstractness, systematicity, counter-intuitiveness, social and institutional nature. Also it lacks meta-conceptual awareness and hypothesis testing like the scientific knowledge.[36]

Alternative conceptions or misconceptions students develop are the results of the interaction between framework theory and scientific conceptions. Being hybrid in nature, they are intermediate and temporary stage of conceptual development (Vosniadou and Brewer 1994). As aspects of scientific information are added slowly and gradually, the coherence of the framework theory is destroyed and gets restructured to be consistent with the scientific knowledge. Unlike exclusive focus by Chi (1994), ontology is one of the elements in conceptual change and takes long time as whole of the network of the constituent elements of framework theory change in the process (Vosniadou and Ioannides 1998; Vosnaidou 2002). For example, novices hold ontological belief that physical objects are solid and stable, that space is organised in terms of up and down and unsupported objects fall in the downward direction. Having epistemological beliefs novices think that the rest is the natural state of objects and motion needs to be explained, and the entities such as force, heat and weight are the properties of the objects. The information they receive and observations they make are constraint by these presuppositions to produce specific explanations. In contrast to Sun, Moon and Earth being astronomical objects in scientific view, they are considered

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[36] Stella Vosniadou, "Capturing and modeling the process of conceptual change," *Learning and Instruction* 4 (1994): 45-69.
Stella Vosniadou, "On the Nature of Naïve Physics," in *Reconsidering Conceptual Change: Lessons in Theory and Practice*, ed. M. Limon and L. Mason (Netherlands: Kluwer Academic Publisher, 2002): 61-76.

physical objects by the students. Day and nights are produced as Sun moves up and down behind the mountain. Flat Earth, spherical Earth, hollow Earth etc., are the synthetic models or misconceptions produced by the interaction of framework theory with scientific conceptions. This is consistent with the diSessa's position that these knowledge elements form the complex conceptual structure of knowledge or theoretically what was proposed by Posner et al. (1982) as 'conceptual ecology'.

Notwithstanding the extensive efforts invested, research seems to fall short of explaining the entire spectrum of conceptual change--both, in terms of diversity of disciplinary domains and age wise progression in cognitive development among students. By and large a general view has emerged that conceptual change occurs over a number of years of schooling and sometimes continues into the tertiary stages (Vosniadou 2002; diSessa 2006). As the field continues to evolve, the contestation and closure of mechanisms of conceptual change has not ended (Özdemir and Clark 2007).

2.3 Problem Solving: Expert vs Novice Perspective

Next to conceptual understanding, students' difficulties with problem-solving are another problem that troubled science educators (Leonard, Dufresne and Mestre 1996; Sawrey 1990). 'Problem solving' involves the application of learned concepts in novel situations. The acquisition of this ability is often regarded as the culmination of the learning process (Kim and Pak 2002). As with conceptual understanding, research suggests that inefficiency and ineffectiveness in problem solving characterizes the traditional instruction models (Leonard et al. 1996). A convincing amount of evidence collected over the decades by science and physics education researchers reinforces the finding (Kotovsky and Simon 1990; Gerace and Beatty 2005).

The cognitive processes required to build knowledge coherence have been the essential focus of this domain of research. Cognitive perspectives in this domain of research are concerned with the identification and documentation of empirical differences between expert and novice problem solving, and in developing a plausible theory to account for those differences (Larkin 1981; Reif and Heller 1982). The framework developed to explain expert-novice differences in cognitive science has guided the bulk of research on science and physics (Gerace and Beatty 2005).

Research has shown that it is not just in the acquisition but also in structuring of concepts where expert and novice differ significantly. A novice's knowledge is sparse and interspersed with gaps, forms of disconnected groping around distinct topics, stored chronologically as it is learned, and often possess singular representations or are unable to relate different representations. On the other hand, experts have a large store of domain specific knowledge, richly inter-connected and interrelated, hierarchical, organized by fundamental principles and integrated into multiple representations of the constituent concepts. This results in an enhanced ability to recall knowledge, and accessing relevant parts of knowledge to the problem at hand; while novices have a poor recall and cannot have access to a particular bit of knowledge unless properly cued with something they have been drilled to accept (Chi, Feltovich and Glaser 1981; Meltzer 2005; Gerace and Beatty 2005).

Experts and novices also differ in their problem solving behavior. Experts employ forward-looking (whereby organisation of concepts leads to the solution) concept-based strategies, whereas novices typically employ backward-looking or end-means (searching hints from the final states or solutions) techniques. Experts often conduct qualitative analysis of the knowledge at hand, especially when stuck, while novices manipulate equations. Experts have a variety of techniques to overcome impediments; novices generally find it difficult to do so, without outside help (from teachers, instructors or advanced students). Experts employ meta-cognitive abilities, but novices consume all available cognitive resources while attempting to solve problems. Finally, experts can and generally do check their answers via alternative methods, while novices have generally only one way to solve the problem (Heller and Reif 1984; Tuminaro and Redish 2007).

Thus the superior organisation of knowledge and problem solving behavior of experts is characterized by the four phases of analysis: conceptual analysis (orienting, exploring); strategic analysis (planning, choosing); quantitative analysis (executing, determining and answering); and meta-analysis (reflecting, checking, challenging and relating) (Gerace and Beatty 2005). Even though experts possess much more factual knowledge than the novice, their superior-problem solving performance is mainly due to procedural knowledge that enables them to bring the right facts and principles to bear on a problem at the right time (Reif and Heller 1982; Hestenes 1987).

Problems typically used in traditional physics teaching are, on most occasions, goal-directed—focusing on specific objectives such as calculating a physical quantity; narrowly conceived -- can be solved by a straight forward application of a single principle, definition or procedure; disconnected – are closely related to the topics and worked out examples recently covered in lectures, or assigned readings and do not usually integrate previously acquired knowledge; and simplistic— ignore most of the complicated, messy physics that is needed to solve real world based problems (Gerace and Beatty 2005). As a result, when faced with problem solving, students tend to engage in a host of unproductive activity rather than cognitive activity that builds and structures knowledge and develops desirable habits of mind required for problem solving. Focusing excessively on the goal of arriving at an answer, they construct an abstract representation of the problem based primarily on the superficial features of the situation, with limited use of concepts. And while employing ends-means analysis (instrumental) to determine a solution path, end up engaging in the manipulation of equations by employing familiar rather than new and unfamiliar instances of the required concepts (Sweller, Mawer and Ward 1982). While emphasizing the derivation of equations and providing exercises in solving end-of-the-chapter problems, the scope for developing other skills is underplayed (Welles, Hestenes, and

Swackhamer 1995).

Apparently, a typical physics curriculum, on most of occasions, leaves students with a deficient repertoire of conceptual and procedural knowledge required to solve problems in specific but distinct domains of science learning. Problem arises when students are faced with novel problems extracted from a variety of physical and imagined contexts. In attempting to impart expertise in problem solving to students, teachers need to be aware of the deeply entrenched and superfluous repertoire of students' cognitive and procedural knowledge impeding the desired goal. Beside this, teachers need to recognize their own tacit skills in problem solving. In the case of physics teaching, this would require analyzing the situation in terms of concepts; interpreting mathematical formalism; employing multiple representations; seeking and weighing alternative solutions; formulating strategies before solving a problem; comparing and contrasting with more familiar situations; and monitoring and reflecting upon their own problem solving behavior (Reif and Heller 1982; Hestenes 1987) .

2.4 Nature of Science (NOS) component in Instruction

The model of 'conceptual change' embeds concepts (both students' and scientific ones) in 'conceptual ecology'— a matrix of ontological and epistemological factors (Posner et al. 1982). Alternatively this entails organic relationship between concepts and nature of science (NOS). Contrary to what was implied, at the exclusion of disciplinary component, students' inductive interpretation of phenomenological experience (i. e. intuitive ideas) absorbed the bulk of these research activities. As a result insufficient stress was placed on the process of acquiring scientific frameworks, reinterpreting experience and transcending common sense reasoning by students (See Hodson 1988; Monk and Osborne 1996; Loving 1997: Matthews 1998; Osborne 2007; Turner 2008).

It was during the early 1990s that overemphasis on students' inductive interpretation of phenomenological experience and the tendency to promote intuitive ideas began to be doubted by a section of science educators (Osborne 1993; Hodson 1988). Now thrust was placed to reverse the trend. Instead of intuitive ideas, the nature of science be given precedence in science and physics instruction was argued. The premise was that the majority of ideas in science, particularly in physics, were essentially counter-intuitive and rather than drawing properties from objects, arose from attributing it to them. The great successes of modern science were the accomplishments of individuals who have transcended intuitive reasoning and used their imagination to devise new ways of conceiving the workings of the world (Chalmers 1982; Wolpert 1992; Duit and Tregast 2003). In this framework, the goal of science education, rather than doing science, is more about 'learning about science'. And this aim can successfully be achieved by exposing students to the nature of science (Taber 2006, 143; Osborne 2007).

Alternatively, the proponents of the NOS have argued for a strong role for the history, philosophy and sociology of science (Hodson 1988; Mathhews 1992, 1998; Monk and Osborne 1996; Osborne 2007; Turner 2008). They observe that science textbooks are written to provide students with a popular, contemporary, cleaned-up, and pre-justified account of the behaviour of the natural world; and therefore, emphasise the context of justification through imparting the products and processes of science (Monk and Osborne 1996, 405). Science is better learned by placing emphasis upon the context of discovery, by giving detailed accounts of how science actually evolved and detailing the kind of reasoning and processes involved. The emphasis on the context of discovery discloses a plurality of viewpoints and alternative interpretations of evidence that could compel science teachers to raise epistemological questions—'how do we know and what is the evidence for it' (Ibid., 414). For students it would become clear that the production of scientific knowledge is a contested process. Hodson (2001) in "What Counts as Good Science Education", sums up the inference that "Science education as a process of enculturation should introduce learners to the knowledge, practice, codes of behaviour, values, styles of discourse, history and traditions of the community of scientists like the craftsman-apprentice relationship. This entails what Barbara Rogoff (1990) called 'guided participation' and Vygotsky (1978) calls the 'zone of proximal development" (12).

The launching of the journal of *Science & Education* in 1990, under the rubric of history, philosophy and sociology of science (HPS) (or NOS), was a stepping stone towards this end. Indeed, a great deal of material has been produced and debated for its absorption in instruction (Matthews 2015). With a view to include or enhance the NOS component in the curriculum, debates on various dimensions of NOS became frequent among science educators. For instance, a group of science educators led by Norman Lederman investigated the views held by teachers, students, scientists, historians and philosophers on seven features of NOS given below (Lederman et al. 2002).[37]

1. Empirical basis of science: The distinction between the empirical observation and inference of theoretical entities corresponds to the distinction between sense experiences and reconstruction of scientific entities.
2. Scientific laws and theories: The scientific law is the descriptive statements of relationship among observable phenomenon while theory is the inferred explanation for observed phenomenon or regularities. Meaning thereby that scientific laws and theories are the different kinds of knowledge and clear distinction between these terms need to be made.
3. Scientific creativity: Generation of scientific knowledge involves human imagination and creativity on the part of the scientists. Science is not a lifeless, entirely rational and orderly activity. Consequently, scientific entities, such as atoms and species are functional theoretical models rather than copies of reality (Lederman et al. 2002, 500).

[37] Norm G. Lederman et al., "Views of Nature of Science Questionnaire: Towards Valid and Meaningful Assessment of Learners Conceptions of the Nature of Science," *Journal of Research in Science Teaching* 39, no. 6 (2002): 497–521.

4. Theory dependence of observation: Scientists have theoretical and disciplinary commitments, beliefs, prior knowledge, training, experiences, and expectations that influence their work. Amidst these antecedents, scientists investigate and solve problems.
5. Cultural embeddedness of science: Science cannot remain isolated and rather is affected and shaped by the larger culture in which it is embedded (Lederman et al. 2002, 501).
6. Nature of scientific method: In contrast to the popular belief there is no single scientific method that would guarantee the development of knowledge in science (Lederman et al. 2002, 502).
7. Tentativeness of knowledge: Scientific knowledge, although reliable and durable, is not absolute or certain. It is subject to change or evolves further (Lederman et al. 2002, 502).

Michel Matthews, one of the major figures in the NOS debates, has supplemented the NOS elements and argued for further refinement of features of NOS (Matthews 2012).[38] According to him, the serious concern of philosophers regarding NOS is not about the reality of the world as emphasised by the Lederman Group, but the reality of explanatory entities in scientific theories. The various philosophical strands such as realists, empiricists, constructivists and instrumentalists concerning ontological entities, need to be given appropriate importance in the curriculum. The second problem with the Lederman Group, according to him, is the characterisation of the non-empirical component of science i. e. the process of abstraction, and idealisation. Matthews advocates the addition of the following elements in NOS framework enunciated by Lederman group:

1. Experimentation as the foundational stone for the progress of science
2. The function and status of idealisation in scientific theorising
3. How do models relate to the world they model?

[38] Michael R. Matthews, "Changing the Focus: From Nature of Science to Features of Science," in *Advances in Nature of Science Research*, ed. Myint Swe Khine (Dordrecht: Springer, 2012), 3-26.

4. Matehmatisation of science or physics
5. Theory choice and rationality
6. Explanation
7. Realism and constructivism
8. Values and socio-scientific issues
9. Technology
10. Worldviews and religion
11. Feminism

Apparently, investigations and production of curricular material along these features of NOS can strengthen the meta-theoretical component advocated in 'conceptual change' model in science learning. [39] Rather than separate treatment, its interweaving with the concept formation, problem solving or experimental process of instruction, is supposed to prove more effective (Duschl 1985; Matthews 1992; Kipnis 1998; McComas, Olson and Joanne 1998; Tseitlin and Galali 2005). Tseitlin and Galali (2005) streamline the probable role of history of physics in curriculum.[40] Firstly, the historical content can reveal the methods and context of the discovery of scientific ideas and theory. Secondly, introduction of the competition among scientific theories can facilitate shedding off misconceptions among students. The idea resonates with science educators rediscovering recapitulation theory—the analogy between the growth of individual and collective knowledge. Thirdly, comparison and contrast between conceptual alternatives and awareness of the extent or limit of their validity can result in the clarity of scientific knowledge; evidently, refuting the view that exposure to erroneous concepts and discourses in the history is a waste of time.

[39] The order of the features of NOS does not imply the order of their importance in the intended curriculum.
[40] The inferences are based on over 150 years' developmental history of science and science education.

2.5 Physics Education as a Domain of Research

School science, for over three-four decades, has grown as a distinctively new area of research. The developments in the domain have impacted the professionalization of physics education at the introductory and undergraduate levels (Docktor and Mestre 2014). The section discusses the nature and extent of the professionalization of physics education via research in the field.

As mentioned earlier, involvement scientists in reforming physics education at the school level had its beginning in the curriculum reform movement during the 1950s and 60s (Cummings 2011).[41] Discovery of the conflict between pre-scientific and scientific conceptions during 1970-80s led to the second wave of reform movement in science education. School physics emerged as the most researched (64%) domain of science where students' conceptual difficulties were first identified and documented by science educators. The studies suggested that the problem was prevalent at all levels of physics education (Rief 1974; Cummings 2011). Following the inroads made by science educators (working on school science), the physics faculties (from universities and colleges) began to take up studies on the problems students confront at the introductory and college levels. Investigations into the nature of the problem spawned a large quantum of literature on students' conceptual difficulties and problem solving in physics (Hestenes 1979, 1998; McDermott 1990; Reif 1996; Redish 1999). Beginning was made with the domain of dynamics and the concepts such as force, motion, momentum, and energy were investigated. Studies then were extended to topics in electromagnetism, thermal physics, waves and oscillation, light and optics, as well as relativity and quantum physics. The studies threw light on the rich vein of the cognitive resources students bring in while grasping and ultimately using concepts in solving problems (Beichner 2009; Cummings 2011; Docktor and Mestre 2014).

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[41] As mentioned earlier, Physical Science Study Curriculum (PSSC), Project Physics, Science Curriculum Improvement Study (SCIS) is the outcomes of this engagement.

There is a wide spread recognition and appreciation of science educators' discovery of the incompatibility between students' pre-instructional conceptions and scientific conceptions and deficiencies in problem solving (Hestenes 1979, 1987; Redish 1999). When it comes to the requirement of theoretical framework on students' conceptions, researchers seem to be divided on the issue. For example, Lillian McDermott, a pioneer in the field, thinks it is enough to know that students' conceptions differ from the scientific ones and prefers to emphasise the ways and means to rectify the problem (Cummings 2011). On the other hand Redish (1994), has suggested cognitive science as the preliminary theoretical framework having its micro-genesis in neuroscience. According to Redish, without a theoretical basis, PER is not more than a series of trial-and-error attempts aimed to improve learning. Though, cognitive issues occupy the core of this research, sociocultural frameworks for testing and guiding collaboration and discourses among the learners, and affective aspects like attitudes and expectations, also form the fabric of the field (Beichner 2011; Cumming 2011; Docktor and Mestre 2014). The inputs from philosophy of science, cognitive science and science education research have been incorporated by Hestenes in proposing model-based view in physics instruction (Hestenes 1987, 2006).

While science educators have been working to reframe the NOS component in the curriculum, physics teachers from tertiary level draw on their experiences. Over the years, physics education research (PER) acquired an interdisciplinary status where physics teachers, science educators, cognitive scientists and even instructional designers work together.

2.5.1 Concept Inventories and their Impact

A concept inventory is a repository of alternative conceptions from a particular domain of science, mathematics or engineering reframed as questions to assess conceptual understanding of the students. Having investigated the nature and quantum of alternative conceptions during 1970s and 1980s, they were put together in the form of assessment tools in the following years. This marks a stepping stone in establishing the credibility of the PER. First concept inventory termed as *Mechanics Diagnostic* (MD) was devised by Halloun and Hestenes (1985) in 1985. The goal of the diagnostic instrument was to measure students' conceptions of motion and its causes in quantitative form. Low pre-test scores were found to consistent across the different student populations.

Subsequent development of this tool in 1992 was named as Force Concept Inventory (FCI). The FCI is meticulously detailed in stating the topics covered and the types of alternative conceptions the instrument aims to detect. Interviews were conducted to probe alternative conceptions or questions. FCI comprises of 29 multiple-choice qualitative questions on kinematics, Newton's laws of motion, superposition principle and kinds of forces designed to explicate conceptual difficulties of students which otherwise cannot be rendered visible by using traditional assessment tools. It requires no problem solving or computational skills like the case with traditional examinations. The choice of a particular distracter gives evidence of the presence of alternative conceptions. For example, in a head-on collision between a large truck and a compact car, students tend to think that truck exerts greater force on the car. Or in case of two balls which except one being the double the mass of the other are equivalent in all respects, students see heavier ball strike the ground earlier when released from equal height (4^{th} and 1^{st} question of the FCI, respectively).

Because of its deceptive simplicity, physics teachers in the initial years were either reluctant or not convinced about the applicability of this tool. They felt the test offends the intelligence of their students and the credibility of their own teaching. However, they were shocked to learn about unexpectedly low scores secured by their students in the test. A breakthrough in accepting the validity of the instrument came in 1992 when the results of the test carried out on a wide variety of institutions across USA were published by Hestenes, Wells, and Swackhamer. The results unquestionably revealed the ineffectiveness of traditional instruction in physics. Eric Mazur, a physics professor at Harvard, was probably the first to candidly accept and appreciate the findings of the FCI. He noted that though his students were able to successfully complete difficult quantitative problems set by him they missed what appeared (to him) easy conceptual questions on the conceptual inventory designed by Hestenes and co-researchers. A few other physics faculties administering FCI were even dismayed. It was found that the personality of teachers (including other factors) did not have a significant impact on students' learning of concepts since their conceptions were deeply rooted and contradicted physics conceptions (Beichner 2009; Cummings 2011).

Advanced version of FCI comprising of 30 questions of qualitative nature was brought out by Wells, Hestenes and Halloun in 1995. Latter while subjecting FCI claims to critical and detailed analysis Heller and Huffman (1995), claimed that FCI distracters do not necessarily capture all possible responses and not in the correct proportions as claimed by the respective authors. This means students have coherent knowledge of Newtonian concepts which FCI does not measure. In defense Wells et al. (1995) defended their claims by arguing that different responses in FCI are mildly related and only students securing 60 to 85% score have coherent understanding of the various concepts being tested or can be termed as Newtonian thinkers.

As an outgrowth of FCI, the methodology of concept inventory and clinical interview, including other tools in physics education research have gained in sophistication and their findings are found to be at variance with teachers' judgements. Now besides Newton's Laws and the related concepts, concept inventories are available in the domains of electromagnetism, thermal physics, wave and oscillations and quantum physics etc. For example, *Rotational and Rolling Motion Conceptual Survey* (RRMCS) by Rimoldini and Singh (2005); *Conceptual Survey of Electricity and Magnetism* (CSEM) by Maloney, O'Kuma, Hieggelke and Alan (2001); *Waves Concept Inventory* (WCI) by Rhoads and Roedel (1999); *Introductory Thermal Concept Evaluation* (ITCE) by Yeo and Zadnik (2001); *Quantum Mechanics Conceptual Survey* (QMCS) by McKagan, Perkins and Wieman (2010).[42] Also concept inventories testing epistemological beliefs held by the students in different domains of physics have been designed over the years, for instance, *Maryland Physics Expectations Survey* (MPEX) by Redish, Steinberg and Saul (1998) and *Epistemological Beliefs Assessment for Physical Sciences* (EBAPS) by Elby (2001)**.** The development and validation of research based tools and methodologies can take a number of years as explication, iterative analysis and interpretation of tests and interviews with students require considerable rigour and time. The use of a research based concept inventory (in other domains of physics) became widely available in 1990s and served as a catalyst in drawing attention of the larger physics education community towards the nature of this problem and the need to resolve it. A number of concept inventories, because they can be administered to a large numbers of students, have substantial statistical power to generalise the results (Mazur 1997).

One of the outcomes of conceptual inventories was the illustration that certain concepts and modes of reasoning must be developed before problem-solving instruction could be effective (Hestenes 1987; Wells, Hestenes, and Swackhamer 1995). According to Hestenes et al. (1992), there exists a kind of threshold of conceptual understanding (mastery of about 60% of concepts), in the Concept Inventory, below which a students' grasp of Newtonian concepts is insufficient for effective problem solving. Below this threshold, it is especially important to take students' conceptions (or misconceptions) into account and sort them out before proceeding to problem solving. An adequate conceptual foundation when built, the way out for the organisation of conceptual knowledge required for problem solving opens up. Most of the work in PER has been on promoting conceptual understanding so far and still

[42] Refer o Libarkin (2008) and https://www.asbmb.org/uploadedFiles/Education/TeachingStrategies/Concept_Inventory/Concept%20Inventories%202%202%202015.pdf to see the typology of concept inventories.

has to evolve further with a series of instructional models on problem solving. Availability of concepts inventory facilitated the designing of new instructional interventions for better conceptual understanding as well as problem solving by the students (Beichner 2009).

2.5.2 Instructional Interventions

Beside diagnosis of students' conceptual difficulties, concept inventories are used to facilitate the construction and testing of the efficacy of the new approaches of instruction as much as traditional ones. Both qualitative (for example interviews) and quantitative methods of investigation have been used to develop an assortment of validated and reliable instructional strategies. When used in-conjunction, these offer complementary insights to enrich learning of physics. Collectively, they are referred as 'interactive engagement' methods of instruction (Hake 1998a).[43] Though diverse in nature, various instructional methods in varying proportions share common characteristics.

Interactive engagements are informed and explicitly guided by research on students' pre-instruction knowledge state and learning trajectory. Learning difficulties or beliefs of the students are elicited and addressed by breaking them into specific qualitative knowledge elements that are potentially productive and useful for quantitative reconstruction of concepts (Hake 2007). Multiple representations such as worksheets, diagrams, pictures, graphs are deliberatively used to translate conceptual understanding and hence promote metacognition across diverse contexts. Having linked concepts into well-organized hierarchical structures, they are used in a variety of problem-solving activities during class time. Problems are posed in a wide variety of contexts and representations. Moreover these instructional interventions frequently incorporate the use of actual physical systems in problem solving.

[43] Interactive engagements are "those designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors" (Hake 1998, 65).

Like the case with conceptual understanding, it recognizes the need to reflect on one's own problem-solving act (Henderson et al. 2012: Meltzer and Thornton 2012).

Active learning and peer cooperation constitute the components of interactive engagement as instructional methodology. Unlike traditional approaches, incorporation of both hands-on and minds-on laboratory activities with teaching is the major component of instruction. The nature of engagement is basically variants of guided-inquiry. Students often work together in small groups and conduct dialogic interaction with teachers and peers by discussing, questioning, predicting, generating data from experimental activity, testing hypothesis, and guidance and feedback by the teachers. Meta-cognition i. e., reflection and expression of thinking and keen monitoring of their actions is encouraged in the students. The instructional outcomes have been tested repeatedly in actual classroom settings and have yielded objective evidence of improved student learning (Henderson et al. 2012: Meltzer and Thornton 2012).

Technological tools such as real-time computerized data collection and display, interactive computer simulations and videos of physical events are extensively employed in a number of instructional interventions. Mathematical modelling and structured problem-solving supplement the concept building process in some of them and are essential components in others. In some cases paper and pencil work actively pursued by students is claimed to result in higher gains in the examination than traditional lectures and homework (Henderson et al. 2012).

Meltzer and Thornton (2012) have classified various instructional methods based on interactive engagement in the following five categories.[44]

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[44] David E. Meltzer and Ronald K. Thornton, "Resource Letter ALIP–1: Active-Learning Instruction in Physics," *American Journal of Physics* 80, no. 6 (2012): 478-496

1. Instruction primarily uses modified lectures such as *Peer Instruction*, *Interactive Lecture Demonstration* etc. *Peer Instruction* constitutes interactive segments of a sequence of lectures, qualitative questions and students' collaborative work to answers the multiple-choice questions based on concept inventories. The reduced lecture time is used for holding interaction between teachers and students (Mazur 1997; Crouch and Mazur 2001). In *Interactive Lecture Demonstrations* (ILDs) teacher performs experiments before the students. Students are asked to make careful observation and predict certain outcomes, discuss with their fellow students and revise their predictions. Very often, teacher leads students to test their predictions by collecting, analysing and modelling data through real time data logging tools (Sokoloff and Thornton 2008; Kozhevnikov and Thornton 2006).

2. Instruction primarily based on laboratory activities, for example *Socratic Dialog-Inducing Labs* by Hake (1992), *Tools for Scientific Thinking* by Thornton and Sokoloff (1990, 1993) and *RealTime Physics* by Sokoloff, Laws and Thornton (2007) etc. *Socratic Dialog-Inducing Labs* use laboratory activities for creating cognitive conflict, multiple representations of the data generated and dialogue between teachers and students. *Tools for Scientific Thinking* is the guided-inquiry conducted in the laboratory. This is one of the first undergraduate curricula using microcomputer and motion sensors for generating real-time data and representing it graphically. Students are asked to make and explain predictions of experimental outcomes and work collaboratively in small groups to test them. Following similar line *RealTime Physics* uses real-time data-logging tools and leads students to build mathematical models of the data generated.

3. Hybrid lecture-lab based instruction, for example, *Model based Instructional Program* by Hestenes and Halloun (1987) and Wells, Hestenes and Swackhamer (1998), *Cooperative Group Problem Solving* by University of Minnesota Physics Education Research and Development Cooperative Group (1996), *Workshop Physics* by P. W. Laws (2004), *Physics by Inquiry* by L. C.

McDermott and colleagues (1996) etc. In *Model based Instructional Program*, students are led to extract data from the experiments and other sources and generate models by the graphical and diagrammatic means. The models are linked to conceptual understanding and theory building thereafter. *Cooperative Group Problem Solving* is a collection of the problems from the context of everyday life situations. The problem may include extraneous information. Unlike traditional text-book problem solving exercises, the target variable is not mentioned directly. Solving problem demands relatively simpler estimations. *Workshop Physics* is meant for calculus-based introductory physics course. Instead of formal lectures, it relies on the computer tools for data collection and constructing models. Like other interactive engagements it is also a collaborative activity between students and teachers. *Physics by Inquiry* integrates quantitative and qualitative problem-solving exercises by the way of hands-on laboratory activities and exposition of textual material provided in the detailed worksheets. Instruction is basically designed for the pre-service teachers and non-science students.

4. *Tutorials in Introductory Physics* by L. C. McDermott, P. S. Shaffer and the Physics Education Group (2003) etc. *Tutorials in Introductory Physics* use worksheets to write qualitative explanations for wide variety of challenging concepts in introductory physics. This is supplemented by the pre-tests, examination questions and notes by the tutor. Homework assignments are used to extend and apply the concepts so developed. Developing intuitive thinking, reasoning and relating concepts to every-day life situations supplement the conceptual understanding emphasised in the tutorials. Annotated video clips are other material providing support to the tutorials.

5. *Computer Simulations and Intelligent Tutors* for example, *MasteringPhysics* and *Interactive Science Simulations*. *MasteringPhysics* by is an online homework program. Tutorial is paced as per the need of the individual students and supplemented by extensive hints and feedback. *Interactive Science Simulation* is

a collection of sophisticated interactive simulations on many topics in physical science.

Sophisticated and scientifically validated though majority of these instructional modules lack well articulated theoretical framework. Hestenes and Halloun appear to stand apart in theorising the instructional module proposed by them. While traditional physics instruction is said to be situated within the positivist science, 'Modeling in Physics Instruction' drew upon the emerging historico-cognitive view (also called model-based view) of science as well as inputs from the emerging field of cognitive science. The shift was caused by the replacement of concepts by models as the unit of scientific theory. From the instructional perspective, model formation begins at the phenomenological or qualitative level through observation and experiment. The empirical data generated from experiments are translated into mathematical equations or empirical models. The mathematical or empirical models so formed are further synthesised to form theoretical models and then are deductively employed in predicting and explaining physical phenomenon. Modelling, quite unlike traditional instruction, bridges the experimentation, mathematical equations or formalism and prediction or explanation of phenomenon, thereby unifying the seemingly diverging approaches of induction and deduction (Hestenes 1987, 2006).

While the expert vs novice research on 'problem solving' was aligned to bring out the tacit and hidden cognitive factors, 'Modelling in Physics Instruction' identified the essential procedural knowledge from a disciplinary perspective. (Hestenes 1987, 2006) is particular in asserting that the problem with 'problem solving' arises from a faulty selection of concept as the unit of knowledge. Model-making rather than concept-formation should be the basic unit of instruction in physics and when implemented, it can potentially resolve not only conceptual and theoretical issues but difficulties encountered by students in the 'problem solving' domain.

'Perceptual Approach' in Physics Teaching developed by Kurki-Suonio (2010) is another example of instructional model analogous to 'Modeling in Physics Instruction'.[45] Similar to 'Modeling in Physics Instruction', the instructional process in this module begins with the requisite amount of perceptual experiences as the base for the concept formation. Very often, physics teachers lament traditional instruction's inability in arousing adequate amount of physical intuition among students. Building on phenomenological or qualitative experiences--observations, demonstration and experimentation to develop perception, the approach promises to rectify the problem. A well-formed storehouse of perceptual experience acts as the base for subsequent learning of concept-formation. With the relevant measurements, qualitative concepts are translated into quantities, laws and theories. Once mathematisation of empirical data is achieved, concepts are formulated deductively like is done in traditional instruction.[46]

Summary and Conclusion

The foundation of the disciplinary structure of physics curriculum was laid down during curricular reforms (1960s) in USA. The axioms and mathematical formalism being at the core, the organisation of the content was rigorous, favouring the preparation of future scientists. Inductive re-discovery of concepts through experimentation—supposedly the way scientists approach science, was popularised as the methodology of teaching physics. Post-implementation analysis of the curriculum suggested that in proposing inductive re-discovery of scientific concepts, both scientists and science educators erred in equiating the epistemology of science with pedagogy (Hodson 1988, 1996; Kirschner and Sweller 2006).[47] Subsequently, while drawing a distinction between epistemology and pedagogy, the role of

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[45] The approach was developed by Kurki-Suonio more than two decades.

[46] Alternative textbooks are the other important outcomes of the physics education research. Refer to McDermott and Redish (1999); Henderson et al. (2012) and Meltzer and Thornton (2012).

[47] Now with the advent of the 'Information Processing Model' in cognitive science, it is conclusively established that unguided inquiry or discovery method demands an unassumingly high cognitive commitment from students and hence is an unnatural method for learning science (Kirschner and Sweller 2006).

experiment as the deductive illustration of theory was clarified and consolidated over the years. Now well-designed experiments and demonstrations were assigned the role of validating concepts and theories. Occasionally, guided inquiry through experimental activity (i. e. hands on learning with the provision of guidance from the teacher) has reappeared in 'project work' undertaken by the students. Broadly, axiomatic-deductive illustration of the subject matter centred on mathematical equations and formalism has sustained as the salient feature of physics instruction. Theoretically this was reinforced by the reformulation of 'expository method' of teaching by David Ausubell (1968). As a matter of fact, induction and deduction, albeit in disjointed fashion, constituted the methodology of physics instruction (Hestenes 1987; Hodson 1996; Trumper 2003).

Despite large scale reforms in the content and methods during the curricular reform period (1950s and 1960s), it did not enable students learn science (and physics) as much as anticipation by the science educators. Conflict between pre-instructional and scientific conceptions was identified as the major reason for the lacuna. Empirical evidence suggested that students' pre-instructional conceptions come in the way of learning science to a significant extent. Pre-instructional conceptions were found to have well evolved structure and help students interpret physical phenomenon around them. As such they happen to be tenacious and offer resistance to change. They diverge from scientific conceptions in not being hypothetical, abstract and counter-intuitive in nature (Driver and Easley 1978; Carey 2000; Duit and Treagust 2003). One of the upshots of these outcomes happened to be the rejection of tabula rasa metaphor of cognition prevalent in the pedagogy of the day (Gil-Perez et al. 2002; Niaz et al. 2003; Viennot 2006)

Having gained empirical insight into the nature of pre-instructional conceptions, science educators set on to theorise the way they can be transformed into the scientific ones. Learning of scientific conceptions was likened to Piagetian ideas of assimilation and accommodation and equated to

Thomas Kuhn's notion of normal science and paradigm shift in science. Conditions promoting science learning in students vis-a-vis dissatisfaction of the existing conceptions and intelligibility, parsimony and fruitfulness of the new conception were spell out. The 'conception' acquired wide-ranging meaning and drew distinction from the prevalent notion of 'concept' in the learning of science. It was generalizable across different levels of education (from elementary to tertiary) as well as the domains of science.[48] Rather than having independent existence, conceptions were seen embedded in a 'conceptual ecology'—a complex of ontological, epistemological, anomalies, analogies and metaphysical beliefs.[49] As an implication, students need to be made aware of their conceptual ecology and fundamental assumptions (Posner et al. 1982; Strike and Posner 1992). It became clear that learning of science (or physics) is a multi-faceted and long-term process (Duit and Treagust 2003).

The 'Conceptual Change' model offered a wide arching framework for conducting further research and debates in science and physics pedagogy. In the early stages of research (in physics and other science disciplines), scientifically incorrect response of students was interpreted as a misconception and thus demanded remediation. With the passage of time, science educators realised that what was termed as an incorrect response or misconception in scientific terms may not be the final unit of a students' conception but the symptom of deeper flaw in their knowledge structure. This turned focus on the elemental view of students' knowledge structures and a new vocabulary such as anchoring conceptions (by Clement, Brewer, and Ziet 1989), phenomenological primitives and coordination class was coined to explicate it (by diSessa 1993, 2002; diSessa and Sherin 1998) and mental models and framework theory (by Vosnaidou 1994). While identification of

[48] In educational practice, the notion is attributed to Jerome Bruner (1966) and comprises the reduction of innumerable and recurring observations and properties of physical phenomenon to an idea or a mental picture.

[49] Term is already elaborated in the section 2.2.2, of this chapter.

the quasi-elemental view of students' conceptions was a breakthrough, identifying the process by which they were constructed became overwhelmingly significant for science educators.

The usefulness of students' conceptions was ascertained. It was revealed that some of them can anchor the understanding of scientific conceptions through intermediate analogical relations. For instance, variation of the phenomenon of springiness via spring and flexible board can help understand the seemingly invisible springy action offered by the table to the book placed on it (i. e. the normal force exerted by table on the book). Phenomenological primitives are the bits and pieces of their phenomenological experiences. These conceptions do not form a coherent structure like a theory as envisaged in conceptual change model. Rather, in response to a particular question or problem, students dynamically organise these pieces and produce right or wrong explanations. They along with other knowledge elements are hypothesised to integrate into concepts (both pre-scientific and scientific ones) and termed as 'coordination classes' (diSessa 2002). Well-nuanced though this stream of research has not yet reached to a stage be impact instruction productively.

'Framework theory' is meant to explain the structure of naïve physics and consists of perceptual experience and information, ontological and epistemological presuppositions and mental representations. Under the influence of culture and language these produce specific explanation for the phenomenon around the learner. Interaction of the elements of framework theory (i. e. naïve physics) with scientific conceptions produces hybrid pieces of knowledge known as misconceptions. Slowly and gradually the coherence of framework theory is destroyed and reorganises to become consistent with scientific knowledge (Vosnoudue 1994, Vosniadou and Ioannides 1998; Vosniadou 2002).

From ontological perspective novice or students have a tendency to attribute materialistic ontology to physical objects and processes around them. Misconceptions arise when materialistic ontological category is attributed to processual phenomenon (see for instance Slotta and Chi 2006). On the other hand experts (or professional scientists) too, as demanded by the the context, attribute materialistic ontology to things. Similarly novices do not always confine themselves to materialistic ontology (Gupta, Hammer, and Redish 2010). However hallmark of learning science is to make shift towards processual or emergent ontology.

Research extended further into the tacit epistemologies and expectations—the beliefs constraining or facilitating the acquisition of physics knowledge. Physics as a coherent conceptual network; primacy of the conceptual content underlying mathematical equations and formalism and active construction of knowledge oneself; were identified as the belief systems of those advancing in the ladder of learning physics. On the other hand, knowledge as pieces of information; instrumental value of mathematical equations and formalism; and reception of knowledge from the teachers and text were ascertained as the epistemological belief system of those struggling in learning physics. Conclusion was drawn that clarification of epistemological belief system of students is a must and need to be pursued as instructional objective (for instance Hammer 1994, 1995)

Significant work has been conducted relating the nature of students' pre-instructional conceptions and the way they can be transformed into the scientific ones, however it did not lead to conclusive end as yet. At the other end 'constructivism'—the umbrella term used for these research, came under severe criticism from some quarters of science educators (Niaz et al. 2003). Like curricular reforms during 1960s, the constructivist movement was labelled to commit the error of confusing students' epistemology with pedagogy. It was argued that this brand of research was more concerned with how students construct their knowledge and less on whether the knowledge constructed is right or wrong (Matthews 2002). As a reformatory move, the science educators' critiquing this programme of research advocated a different line of research. Large scale research into the nature of science (NOS) and its introduction in the curriculum was initated. Inadvertently though, this brought back 'conceptual ecology' albeit replacing the meta-cognition of students' learning with the meta-theoretical awareness of scientific conceptions. Seen from the conceptual-ecology perspective, introduction of nature of science (NOS) in science education can be termed as the conceptual-ecology of science. A well-explicated conceptual-ecology of science (i. e., NOS) is supposed to help students contrast and resolve the inherent inconsistencies in their pre-scientific conceptual-ecology (Posner et al. 1982; Strike and Posner 1992).

The launch of the journal of *Science & Education* in 1990 was a landmark step undertaken to develop the content and methodology on NOS. With the course of time science educators came up with a framework for the nature of science elements in the curriculum. As an exemplar of the work on nature of science elements, empirical basis of science, scientific laws and theories, scientific creativity, theory dependence of observation, cultural embeddedness of science, nature of scientific method and tentativeness of knowledge are proposed by the Lederman group (2002). Experimentation, idealisation, model-making, mathematisation, theory choice and rationality, explanation, realism and constructivism, values and socio-scientific issues, technology, world views and religion and feminism are the other elements suggested by Matthews (2012) to complete the framework. With this advancement, NOS component in science education is poised to make further advancements.

Entry of physics faculties in pedagogic research was another stepping stone in this field. Soon after the discovery of students' pre-instructional conceptions by science educators, physics researchers and teachers from colleges and universities realised the shortcomings in the content and methods of traditional physics instruction and took up their own research as a corrective measure. Unlike science educators delving deeper into the quasi-elemental nature of students' pre-instructional conceptions, the majority of physics faculties confined themselves in developing concept inventories and instructional modules. Alternative conceptions are reframed as questions in concept inventories. Though, elemental version of alternative conceptions did not find direct and explicit mention in the lexicon of physics teachers, ontology, epistemological beliefs and anchoring conceptions have been incorporated to design the questions of the concept inventories. In fact a few of the concept inventories are solely based on the epistemological beliefs. Most of the instructional modules focus on the resolution of conceptual problems, some of them also take up the problem solving and model making as well. Majority of physics educators treat model-making and mathematisation implicitly or without backing with the theoretical justification. Hestenes (1987, 2006) and Halloun (2007) have grounded the instructional modules on broader theoretical foundation. It is notable that Hestenes and Halloun have proposed the replacement of concept-formation by model-making as the unit of scientific knowledge in instruction--the case with traditional mode of instruction. Models are claimed to bridge the gap between concepts and theory on the one hand and experimentation and mathematical formulation of theory on the other.

Moreover, most of the physics education researchers (PERs) do not seem to refer to science educators' work on nature of science (NOS). They did not take up their own research in philosophy, history and sociology of science or physics. As they seem to prefer to draw upon their own experiences as physics teachers, formulation of NOS material for instructional purpose cannot come by. Lacking in developing nature of science perspective, they do not seem to encompass the entirety of problems physics pedagogy is confronted with.

Chapter 3

Physics Education in India: 1970-1995

Indian Association of Physics Teachers (IAPT) was founded in 1984 with the aim of renewing physics education in India (IAPT 1984, 2-3).[1] Since then, the association has undertaken several programmes and activities towards this end. Understanding of the scenario that shaped the Indian physics education prior to the formation of the association becomes pertinent to map out its work. Though the period 1970-1984 is crucial in this regard, it extends to the first half of 1990s. The chapter explores the major policies and programmes undertaken in India to renew the undergraduate physics education during this period. In particular, chapter throws light on the pedagogical orientation emerging out of these engagements.

3.1 Developing a Framework for Physics Education: Srinagar Conference, 1970

The first major attempt to comprehensively analyze the problems of education in independent India was made in the early 1960s by the Indian Education Commission (1966). Taking cognizance of the indigenous needs and problems of the country, the commission developed an in-depth and comprehensive view on all facets of education extending from the elementary to tertiary stages**.** The report of the Education Commission stimulated efforts to formulate an extensive program for the reconstruction of education. Besides other concerns, science education and research was given a high priority in national development.[2]

In tertiary physics, a concerted nationwide interrogation was initiated in 1968. The aim was to translate the recommendations of the commission into a viable plan of action. Consequently, an international conference on physics education and research was held at Srinagar in June 1970 where physicists

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[1] Refer to IAPT's Portal at www.iapt.org.in/www.indapt.org

[2] See the report of the Commission (1964-66), especially the section on science education (389-421).

and physics educators from India, USA, U. K. and Canada deliberated upon specific measures to reform tertiary physics education in India. D. S. Kothari, formerly, the chairperson of the Indian Education Commission, steered the conference. Being a prominent physicist and educationist, he exhorted the participants to formulate a viable action plan to implement the recommendations of the commission. While specifying the nature of the problems of tertiary physics education, a comprehensive program was chalked. The proceedings were documented in the book entitled *Physics in India: Challenges and Opportunities: Summary of proceedings of the conference on physics education and research (Srinagar 21-23, June, 1970)*.[3] The engagement of the Indian contingent with their foreign counterparts was particularly enriching. The countries mentioned above had already made significant progress in this direction and the Indian contingent claimed to benefit from their experience. In particular, discussions with the participants from USA appeared to be significantly beneficial. D. S. Kothari wrote:

> For the past two or three years the physics community in the United States has become increasingly aware of the need to redefine its goals and methods in order to make physics education and research more relevant to the needs of American society. Thus the US and Indian conference delegates discovered that they shared many common concerns, and the dialog was both fruitful and specific. Members of both delegations were stimulated by the experiences of their foreign colleagues and were able to formulate ideas applicable to situations in their own countries. It is hoped that the conference delegates will remain in contact with one other, and perhaps meet periodically to review their recommendations in the light of their further experiences.[4]

Spread over nine days, the interaction involved a comprehensive review of tertiary physics education and recommended specific measures for their resolution. While reiterating the observations of the Education Commission (1966), delegates and participants observed that physics education in India during that period was characterised by rigid and stereotyped curricula and

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[3] UGC and UNESCO, *Physics in India: Challenges and Opportunities – Summary of proceedings of the conference on physics education and research (Srinagar 21-23 June 1970)*(New Delhi: UGC and UNESCO, 1970).

[4] Ibid., preface, paragraph no. 3

examinations, apathetic teaching and research programs as well as inadequate funding to support them (Ibid., 1). The specific recommendations were directed to the central and state government authorities, university administrators, and individual departments and teachers etc. The recommendations had far reaching significance in charting out the future course of action in reforming tertiary physics education. In the following is provided the summary (by extracting the points from chapter 1st, 2nd and 5th of the document) of the deficiencies identified and measures recommended by the conference.[5]

1. Administratively, the need was felt to decouple colleges and universities from the monolithic and centralized systems of education. The move was intended to promote local initiatives. Stronger links between individual teachers and physics departments on the one hand, and the departments of physics in colleges and university and the local industries on the other, were to be established. If the local response was positive then, many of these recommendations, even without requiring further substantial changes in the administrative structure of the universities or large financing on the part of a government agency, were supposed to produce the fruitful outcomes. The multiplicity of such a coherent local initiatives was considered indispensable for the vitalization of physics education in India. The lack of organizational flexibility and freedom, among other problems, faced by the colleges affiliated to the universities, was believed to lead to difficulties in uniformly implementing the suggestions across the colleges in different universities. It was therefore suggested that 5 or 6 affiliated colleges could be grouped together (Ibid., 10-13).

2. Physics courses were envisaged to be more broad-based. Cultivation of the habits of inquiry, experimentation and logical thinking were suggested to replace the teaching of the facts of science. To make it feasible, fewer thematic topics with an in-depth treatment were suggested (Ibid., 11). Instead of

[5] Ibid., *Chapter-I: Summary of Recommendations*, 1-4.
Ibid., *Chapter-III: Teaching of Physics*, 10-21.
Ibid., *Chapter-VI: Special Projects*, 39-44.

promoting rote learning, it was recommended that teaching should give primacy to the clarification and development of concepts. Large scale involvement in problem solving was expected of students when they undertook research in physics. To translate this into reality, students needed to apply knowledge of basic principles of physics to diverse and varied physical situations (Ibid., 3-14).

Laboratory work, it was asserted, should not merely consist of routine experiments but emphasize the development of skills leading to ingenuous experiments enabling students to investigate physical phenomena, deduce relationships and apply their knowledge to solve new problems. A few projects or open-ended experiments carried out in-depth were considered worth pursuing. The colleges were expected to accord specific importance to the development of open-ended experiments. The students with higher abilities were supposed to have the autonomy to opt for an in-depth investigation of the problems. Evidently, this type of laboratory required a greater amount of personal involvement of the teachers. Smaller groups of students were considered as a suitable unit for rendering optimal interactions in the undergraduate laboratory. Provision was made for establishing a workshop for fabrication and maintenance of equipment and providing students opportunities to acquire fabrication skills essential for worthwhile laboratory work (Ibid., 15-16).

3. Instead of testing and reinforcing the teaching of facts, examinations were proposed to comprise of problem-solving questions to judge originality of thinking and organization of knowledge in the students. Increasing use was to be made of oral examinations, particularly at the post graduate level. A voluntary examination for the students about to pass out bachelor degree programme was proposed to be conducted by an appropriate national agency. This was supposed to serve as an index of aptitude of the students for pursuing research carriers in future (Ibid., 2).

4. To develop instructional material, 'science teaching centers' were proposed to be established in association with the Universities. Such centres would not only design and develop prototype equipment, kits, film scripts and

curricular material such as textbooks, teachers' guides, laboratory manuals and methods of teaching, but would also provide support to the colleges and universities in implementing their plans (Ibid., 39-44).

5. The formation of Indian Physics Association (IAP) was recommended to provide physics teachers and researchers a forum for discussing the problems of physics education and research (Ibid., 30). The association needed to have strong regional chapters. Also launching of *Indian Journal of Physics Education* was proposed to stimulate work on physics education as well as disseminate it among teachers, students and researchers (Ibid., 29).

6. Orientation programs for teachers was proposed to be thematically and structurally transformed. This was in the context of the summer institutes organized by UGC for orienting college physics teachers without follow-up programs. The same pattern of the orientation program was followed by numbers of Universities and was regarded a big shortcoming. Now it was considered essential that Universities on continuing bases needed to take up progressive and durable orientation programs followed by sustained follow-up activity (Ibid., 20).

3.2 University Leadership Program (ULP) and College Science Improvement (COSIP) Program

Immediately after the formulation of a scheme for reforming tertiary science education at the Srinagar Conference, in June 1970, the University Grants Commission (UGC) initiated the University Leadership Program (ULP) and the College Science Improvement Program (COSIP) to actualize the recommendations of the Conference. D. S. Kothari, having presided over the Education Commission (1966) as well as the aforementioned Srinagar conference on Physics Education (1970), became the chairman of the UGC committee for faculty development and curricular reforms (Kumar and Nigavekar 1994; Joshi 1997, 323-327).

The basic purpose of the College Science Improvement Program (COSIP) was to initiate a qualitative renewal of the entire spectrum of undergraduate science disciplines, namely, physical, biological, earth and mathematical sciences.[6] A few of the colleges affiliated to various universities were selected and given special grants for upgrading their science courses, which in turn entailed the development of specific programs to revise their curriculum and syllabi, teaching methods and materials, laboratory equipment and workshops, and library facilities (UGC 1982).

University Leadership Program (ULP) was assigned to 40 departments covering the bio-sciences, chemistry, physics, zoology and mathematics. The major objectives of the program was the development of text books, laboratory manuals, films, slides and new laboratory equipment for undergraduate and postgraduate sciences through the involvement of university departments (Ibid., 1). Iterative trials were held throughout the decade and faded towards the early 1980s. With a view to promote use of the materials developed, the University Grant Commission (UGC), in April 1978, sent a circular to the forty aforementioned ULP departments to furnish information on the work accomplished. In response, a number of physics department submitted syllabi and courses of study, laboratory equipment, library and other teaching materials as displayed in table 3.1.[7]

Rajasthan, Poona and Punjab Universities figured as the centres accomplishing relatively better work (Kumar and Nigavekar 1994, 14; Joshi 1997, 323-327). The work produced by Rajasthan University on physics experiments under the leadership of Babulal Saraf is considered exemplary among all the ULP Programs.[8] The aim was to develop conducive and relatively less expensive experiments suitable for the colleges around the

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[6] It is not clear whether the COSIP and ULP in other disciplines followed from the recommendations of the Srinagar conference or was the outcome of similar deliberations conducted.

[7] UGC, *College Science Improvement Programme (COSIP): Teaching Materials developed for use in Classroom and Laboratories for Undergraduate Science Instruction,* (New Delhi: UGC, 1982), 2.

[8] As shown in the table 3.1 books and experiments also came up from other Universities, however, they do not figure as exemplar.

country.[9] The philosophy behind the efforts and other practical details were published in the two volumes of the book *Physics through Experiment*.

Table 3.1 Nature and amount of the work conducted at various ULP centres

S. No.	University/ institution	Textbook	Other reading material or books	Demonstration equipment	Lab. equipment	Teaching aids
1	Bangalore	Printed(1)	----	1	1	----
2	Nagpur	----	Books 2 printed, 1 cyclostyled) Manuals (13 cyclostyled),	----	11	(1 slides)
3	Ranchi	----	-18	-----	57	----
4	Madurai Kamaraj	----	2 manuals	-----	1	3
5	Punjab	----	Books (7 printed, 5 cyclostyled)	----	4	----
6	Andhra	1 under-print	--	-----	36	22
7	Mysore	----	Manuals(1 print, 5 cyclostyled)	----	7	Some slides, models and few kites
8	Rajasthan	----	Books (3 print)	----	32	----
9	Poona	----	--	----	10	1 film
10	Bombay	----	10 manual	----	21	---

The experiments described in the book, did not merely have the technical finesse but could be utilized to demonstrate a number of advanced concepts (Saraf 1979). The text provides a detailed description of the instruments and experiments on electricity, magnetism and electromagnetism (see *Physics through Experiments-Volume I*) and a number of experiments dealing with collisions, potential energy, various facets of oscillatory motion and torsional transmission lines (see *Physics through Experiments-Volume II*). The centre earned wide spread recognition for this work. Subsequently, several colleges affiliated to the University of Rajasthan and the institutions around the country purchased copies of the experiments in mechanics, statistical physics,

[9] Babulal Saraf et al., *Physics through Experiments-1: EMF Constant and Varying,* 2nd Ed. (New Delhi: Vikas Publishing House PVT LTD, 1978).
Babulal Saraf et al., *Physics through Experiments-2: Mechanical Systems-Study of some Fundamental Processes in Physics* (New Delhi: Vikas Publishing House PVT LTD, 1979).

waves and oscillations and thermodynamics (Kumar and Nigavekar 1994, 21). While acknowledging the especially high quality of the work pursued at the physics department, UGC in 1978 instituted a separate centre called Centre for Development of Physics Education (CDPE)" at the University of Rajasthan (Vigyan Prasar 2009; Lokanathan 2009).

Laboratory development was undertaken at other places too, though perhaps not at the same scale as in Rajasthan. Laser-based optical experiments developed by Sirohi at Indian Institute of Technology (IIT), Madras; solid state experiments developed by Nigavekar and colleagues at Pune University; in nuclear physics at Mysore and Bangalore and IIT, Kanpur, were considered worthy of mention (Kumar and Nigavekar 1994, 22).

The COSIP-ULP ran through the 1970s and generated considerable activity. Some of the centres organized orientation programs for teachers, familiarizing them with material and the design of experimental apparatus. One of the fruitful outcomes of these projects was the increased interaction between physics departments in the universities and affiliated colleges (Kumar and Nigavekar 1994, 20).[10]

3.3 Indian Physics Association (IPA) and Journal of Physics Education (JPE)

The formation of the Indian Physics Association (IAP) as an association of researchers and teachers of physics was another significant step following the recommendations of the Srinagar deliberations. Since then, the IAP has been working for the promotion of physics research and education, its advancement, dissemination and application in India. The association claims to promote active interactions among researchers, teachers, students, related

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[10] In the only study of its kind, citing a survey conducted in Guru Nanak Dev University and few other colleges in Chandigarh on the perception of the work on physics education produced by ULP-Chandigarh, Virk (1985) contended that in the opinion of the majority of the teachers implementing the books prepared under ULP-COSIP needed improvement. Notwithstanding, in general, the majority of the teachers were in favor of introducing new COSIP experiments prepared at other ULP-COSIP Departments and the Centre for Development of Physics Education at Rajasthan University, Jaipur. In the opinion of Kushwaha and Hans (1984)) who were involved in the ULP-Chandigarh too, the curricular material on laboratory experiments was well appreciated by the teachers.

bodies and institutions (private or state owned) and interested industries. It also publishes a newsletter called *Physics News* to disseminate materials of on physics research and education. In addition, seminars, lectures, debates, panel discussions, conferences and film shows on physics research and teaching are organised by the association.[11] The interactions among researchers, teachers and students of physics, extend over the local, national and international levels.[12] However, a section of physics faculty argued that the activities of IPA were aligned towards research in physics and the educational component received secondary treatment. This paved the way for the formation Indian Association of Physics Teachers (IAPT), in 1984 (Joshi 1997, 323-327).

Complementing IPA, the *Journal of Physics Education* (JPE) was launched by the Ministry of Human Resource Development (MHRD) in 1973 to provide a channel for promoting, sharing and disseminating the work on physics education.[13] After passing through a phase of closure and reopening, the Department of Physics, Pune University, assumed the charge of running the journal in 1984 (Kulkarni 1997). As a result publication of the journal stabilized thereafter.[14] In April 1999 UGC withdrew its support to the journal and consequently it came to the brink of closure. As a matter of policy to support work on physics education, IAPT came to rescue the journal and has

[11] The entire October 2011 issue of the *Bulletin of IPA*, is dedicated to PER. Introductory articles on the field of PER were written by Arun Kumar and Pratibha Jolly, respectively. The research papers and authors are: Students' conceptions by Atanu Bandyopadhyay and Arvind Kumar; concept inventory by Vijay. A. Singh; PER in laboratory settings by Sahana Murthy; and epistemological beliefs and expectations by P. K. Ahluwalia and Sapna Sharma.

[12] See the portal of *Physics News – a bulletin of Indian Association of Physics*.

[13] MHRD was then known as Ministry of Education and Special Welfare.

[14] After six years the journal was taken over by UGC in 1979 along with the journals in other areas of science. The journal in physics was published by Mysore University and was called *COSIP News Bulletin*. This bulletin ran from 1979-82. Both these journals were locally printed and distributed free to interested institutions and individuals (Joshi 1997). Latter, *Physics Education* along with other journals viz, Chemistry Education, Biology Education and Mathematical Education were revived again in 1984. Publication of two categories of articles and papers were promoted in the new version of the journal. The first category comprised of literature from the domains of physics research describing hypothesis, discoveries and applications. The second category was supposed to deal with educational issues such as teachers' pedagogical experiences, reports of physics education research or the opinions of authors on the contents of syllabi, courses and ways to enrich them.

been nurturing it since March 2001 (IAPT 2001).[15]

3.4 Impact of the Physics Education Programmes on Practice

Of the recommendations of Srinagar Deliberation ULP and COSIP, IPA and JPE were translated into reality. On the other hand formation of science teaching centres for the institutionalization of the developmental activities in physics education remained unrealised. These centres were supposed to develop content regarding concepts and problem solving; develop new and innovative experiments; and provide orientation to the teachers for absorption of this material in their teaching.[16] It is interesting that after so many decades, the centre has still not come into existence. What does it imply? Is it due to the lack of procurement of funds from government agencies or lack of interest of mainstream physicists in education? Scenario prevails, even after physics departments in various countries for long have been conducting researches in physics education.[17]

The lack of progress is also reflected in the measures undertaken in examination reform from 1970.[18] In a bid to make a shift away from the teaching of facts and rote learning, a 'question bank' comprising a large numbers of questions on conceptual understanding and problem solving in undergraduate physics was produced. Similar attempts were made by the Curriculum Development Committee (CDC) during 1988-90 (Joshi 1997, 325). The CDC underlined the importance of the 'problem solving' component. The

[15] Bibliometric analysis of the journal is conducted in the chapter 7.

[16] The idea was also mooted in almost all the major national level deliberations such as Srinagar Conference on Physics Education in 1970, Curriculum Development Committee (CDC) report in 1989, Nigavekar-Kumar report on physics education in 1994 or UNESCO Foundation Course on Physics in 1997.

[17] Most of the research activity in physics education appears to be limited to research institutions like Homi Bhaba Centre for Science Education (HBCSE) and a number of Regional Colleges of Education under the National Council of Educational Research and the Department of Education in some universities. It is only recently in 2010 that seminars on physics education research was organized at Allahabad University by Mehrotra (2010) and those on doctoral research held in Himachal Pradesh University by P. K. Ahluwalia (2009} and Sapna Sharma (2011), and Guru Nanak Dev University by Paramdeep Singh (2011).

[18] However, in the absence of a follow-up report it is not clear which universities and colleges employed the question bank and its impact, if any.

'question bank' consisting of over 400 illustrative problems selected from different sub-domains of undergraduate physics was recommended as part of the syllabus of various universities (Kumar and Nigavekar, 1994, 21).[19] What was the impact of the dissemination of the 'question bank' on the practice is not clear because of the unavailability of documents if any? The effort did not lead to the development of a standard examination (see the recommendation of the Srinagar Conference summarized earlier) for undergraduate physics students. Kumar and Nigavekar observed that examinations at different levels, to a large extent still seem to rely on testing of the derivation of mathematical expressions and factual knowledge. And instead of solving novel problems examinations are more like a substitution exercise. They suggested:

> …In this connection teachers would be greatly benefited if they can access solutions to problems of standard textbooks at undergraduate and postgraduate levels. This might appear like spoon-feeding but is necessary to make a start in introducing problem solving in tertiary physics education. An agency like IPA or IAPT can initiate the preparation of a large compendium of advanced problems in physics with solutions. Ultimately, however, a problem-solving culture will be ingrained in college only when good problems are a part of the examinations.[20]

Following these remarks, it is apparent that large scale introduction and proliferation of concept and 'problem solving' questions in the examinations has not percolated in to the colleges in India. Moreover, research evidence (i. e. Concept Inventories) has amply demonstrated that very often traditional examinations are unable to measure what they purport to do (Rebello and Zollman 2005; Beichner 2009; Cummings 2011). In the absence of scientific validation of aforementioned question bank, its claim for being a reformatory measure may be questionable.

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[19] CDS is described in the forthcoming sections.

[20] Arvind Kumar and Arun Nigavekar, "Physics Education," in *Physics in India: A Status Report,* ed. S. S. Jha (Indian National Science Academy (New Delhi): A Diamond Jubilee Publication, 1994), 22.

Likewise the lack of renewal is also reflected in the teacher training programmes. These programs were supposed to introduce teachers to the novel content and methods. Joshi (1997, 323-327) makes an observation in this regard. According to him, irrespective of the stature of the departments and institutions, orientation programs for teachers often consist of routine lectures on contemporary and advanced topics in physics. He could only express dismay on the reproduction of tradition? In a similar vein, Khandelwal (1994, 68) has termed it unfortunate that orientation programmes for teachers rarely make 'problem solving' and 'training in laboratory physics' a theme for teachers' training. Furthermore, Joshi and Tillu (1989) lamented that refresher courses for teachers do not ground teachers' training on mathematical and conceptual aspects of physics. Similarly, Kumar and Nigavekar (1994) invoke the well documented evidence via *concept inventories* that traditional methods of teaching do not help develop conceptual understanding and teachers' orientation programmes appear to be uninformed with contemporary developments.[21] Apparently the content and methodology of these programs mirror the perpetuation of the existing practice.

3.5 Curriculum Development Centre (CDC)

The reformulation of a model curriculum for undergraduate and post graduate science courses was the next task undertaken by UGC in 1989. Curriculum developers from various universities and institutions across the country deliberated the issue at Pune University. The task force was coordinated by Arun Nigavekar. The committee suggested a number of measures for reorganizing the teaching learning process at the tertiary level. The recommendation was to organize syllabus in terms of a large number of modules introducing flexibility in the course structures. Each module integrates different modes of instruction: classroom teaching, tutorial, laboratory tutorial and laboratory work. Continuity through successive modes of instruction was emphasized. For instance, the laboratory tutorial

[21] See the discussion on *concept inventories* in section 2.5.1, page no. 52, chapter 2.

was an interface between classroom and laboratory work, devoted to instruction about experiments, discussion on sensitivity and precision of measurement, analysis of data, and demonstration of experiments. Secondly, the Committee recommended a uniform pattern for education across the country. It was believed that the curricular outcomes were especially useful for those new universities where manpower for curriculum development was absent or inadequate (Kumar and Nigavekar 1994, 20-21; Joshi 1997, 323-327). Were the recommendations implemented in any university? What were the results? Lack of data on the subject limits anything to say about the subject.

3.6 UNESCO Foundation Course

UNESCO, in 1993, entrusted a 'University Foundation Course in Physics'--a prototypical course termed to be appropriate at the intermediate stage between school and college physics--B.Sc. first year, to some of the developing countries. In India, the development of this course was carried out by a group of physicists from Pune. The model was termed holistic in the sense that rather than dividing content into different domains, it emphasized the development of an integrated world view of physics. The theme is reflected in the title of the textbook *World View of Physics* (Nigavekar 1999, preface of the book). Published in 1999, the course (in book-form) was reportedly accepted by UNESCO for dissemination in the developing countries (Joshi et al. 1999).

'Lectures with demonstrations' instead of just a verbal exposition of the concepts, comprised the first component of the instructional module. Making a departure from the conventional courses, exposition of the concepts was woven together with demonstration activities. The teacher is assigned the task of providing illustrations of a physical concept or principle by performing a demonstration experiment. This is meant to impart a brief qualitative experience to the students. As such it was expected to result in a considerable reduction in the effort invested in the lecture and blackboard work and help students understand the concepts clearly and retain them for a longer period of time (Joshi et al. 1999, 329-330).

Secondly, the provision of tutorials based on questioning and discussions was supposed to increase interaction between the teacher and students. Following this approach, students were to be involved in the formulation of derivations. In place of routine ‘problem-solving’ founded on a mere formula-substitution exercise, the activity extends to the reexamination of the mathematical derivation and linkages between concepts constituting the problem.

The laboratory tutorial, as the third component of course work was meant to introduce group experimental activity to the entire class. This consisted of two parts. The first part dealt with experiments that were close to demonstration. However, unlike demonstrations, they were not limited to the qualitative treatment alone i. e. demonstration of the quantitative variation of physical entities was essential part of the treatment. As a major departure from routine, one or two students would take charge of the experimental activity, vary the parameters and record the readings and later present data before their classmates for joint analysis. Here, the students were encouraged to develop their own interpretation of the data even if it were at variance with the standard one at first or was not mentioned in the textbook or talked about by the teacher. The second part comprised historically significant experiments and therefore was to be discussed in the related historical contexts. This was essentially an exposition of the nature of physics reflecting the intimate and intricate relationship between theory and experiment (Joshi et al. 1999, 330-332).

The fourth and last component of the course comprised experiments to be performed by students individually. Instead of verifying a law as was usually the convention, they were to be basically open-ended experiments with no restrictions on the range of the parameters to be taken up. The handling of equipment, recording, analysis and interpretation of data were now expected to be independently acquired by the students and not dictated by the teacher. The students were required to think and decide which parameters were to be changed and left to decide what consequential changes they would wish to observe. Even while selecting` and setting the devices, the responsibility lay more with the students. No attempt was made to describe or give the theory of the measuring instruments separately; learning was a part of the experimental work itself. This open-ended experimental activity was extended to the whole semester or session. The sole purpose behind carrying out such an experiment was to create the scope for deeper and joyful learning (Joshi et al. 1999, 332).

The structure of the syllabi appeared to be similar to the one enunciated in the CDC guidelines mentioned earlier. The impression does not seem untenable since the chairperson of the committee was Arun Nigavekar—one of the key members in UNSECO project. May be the guidelines prepared during CDC served as the blue print for the latter in 1993. Clearly, first three phases of instruction is built on dialogic interactions among students and teachers. Having created the scope for the construction of knowledge, module is akin to a number of 'Interactive Instructional modules,' produced in PER (Meltzer and Thornton 2012).[22]

Even when the course lays stress on the experimentation and generation of quantitative data from experiments, it does not appear to lay emphasis on the mathematisation of experimental data or mathematical modeling—a major cause for students difficulty in learning physics (Hestenses 1987, 1998, 2006; Halloun 2007; Kurki-Suonio 2010). Indeed students are being involved in derivation of mathematical expressions and solving problems, however, it appears to limit the process to logical procedures. This does not appear unintentional. According to authors "Mathematics is an essential part in the formal study and advancement of physics, but one has to remember that mathematics can at best handle idealized situations, whereas physics extends and nearly approximates to real-life situations. There is a great deal of physics which can be handled with simple mathematical techniques. Similarly it helps, not hinders, the communication of physics if one bypasses much of the

[22] For example, *Peer Instruction* proposed by Eric Mazur (1997).

mathematical structure, which may be of use only to the few select "experts"" (Joshi et al. 1999, 1). Clearly the explication of the connection between experimental process and mathematical modeling is not advocated.

Having made provision for a well-structured teacher guided instructional experiences in first, second and third phases, instructional module proposes students to conduct open-ended experimental activity autonomously in *World View of Physics.* Though, in fourth phase, the idea of an autonomous learner appears to resemble the 'inductive rediscovery' of scientific concepts already experimented during the curricular reforms in 1960s. The idea was discarded in favor of guided inquiry in succeeding decades (Hodson 1996; Duschl 2008). Consequently, instructional modules (i. e. interactive engagements) in PER have created a considerable scope for teachers' expertise and guidance. Lately, the findings of cognitive psychology have supported the idea of replacing un-guided inquiry by teachers' guidance. The contention is made that cognitive load caused by unguided activity is untenable. Ideas are learned on long term basis to form the long-term memory needed to carry out independent inquiry. Meaning thereby only after a number of years acquisition and consolidation of conceptual and procedural knowledge through teachers guidance and support students can independently carry out inquiry themselves (Kirschner, Sweller and Clark 2006). Hence the presupposition that having received teacher structured and guided experiences substantially (in the first three phases of instruction), students can autonomously carry out open-ended experiments need to be subjected to a fair amount of empirical validation before it can make a claim for renewing physics instruction as foreseen by authors.

3.7 Pedagogical Implication of Physics Education in India

The ULP and COSIP were concluded towards the end of 1970s.[23] The major pedagogical outcome spanning these engagements was built around the re-

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[23] Though the projects ended towards the end of the decade of 1970, the work was summed up with publication of *Physics through experiment (*1978, 1979) and *Proceedings of the International Conference on the Role of Laboratory in Physics Education* (1984).

conceptualisation of the role of experiment in concept formation and their large scale production and deployment in the instructional process.[24] The work produced by Babulal Saraf's group has been the prominent among all the efforts. The work appears to place experimental activity at the centre stage in the renewal of physics pedagogy. An extract from Saraf's writing from the preface of the book *Physics through Experiment* (1st volume) suffices the assertion. He stated:

> Now I must speak something about the Philosophy of the academic work that we have done in the field of laboratory improvement. It is true that we did have some conceptual thoughts when we started. We had one objective of generating physical phenomenon in such a way that students throughout the realm of physics could understand it with equal ease and comfort. Secondly we aspired to magnify the physical parameters to such an extent that conceptual ideas could come within the realm of perception. Third we aspired to make physical quantities measurable with sufficient accuracy, such that the correlation law could be derived with sufficient emphasis. These are perhaps the only major objectives which we had in mind and to some extent we have succeeded.[25]

Saraf (in the preface of Saraf et al. 1978) elaborate further that experimental activity should be treated as a source of developing an understanding of a particular phenomenon and not to be limited to just invoking and illustrating what has been taught in theory. For instance, the experiment on the 'charging of a capacitor' should act as an equally strong referent or source for understanding the phenomena. Having been exposed to experimental activity, students should not rely solely on theory to know that charge on a capacitor grows exponentially with time or appreciate the reversal of the current in the circuit when the capacitor discharges. This method is at variance with the narrow and exclusive focus on obtaining the final value of

[24] The *Proceedings of the International Conference on the Role of Laboratory in Physics Education* is testimony to this claim. The book was a compilation of papers presented at the International Conference at Jaipur in 1983-84 (from 29th Dec to 2nd January 1984) by the ULP and COSIP workers from across the country on the role of the laboratory in the teaching of physics. Indeed, it was the culmination of the efforts invested by a section of the Indian physics education community and therefore has a historical significance.

[25] Babulal Saraf et al., *Physics through Experiments-1* (1978), 6.

the capacitance through traditional experimental activity. Moreover, procedural knowledge i. e., learning how to refine or improvise the processes of design, measurement and analysis is considered prerequisites for attaining a conceptual understanding. For instance, while taking example of Air-Track Experiment, Saraf stressed that one has to ensure horizontality of the track, absence of air-currents, symmetric placement of magnets on the rider, absence of unwanted magnets or magnetic material or metals in the neighborhood, etc (Ibid, x-xii).[26]

Saraf's view was reinforced by D. P. Khandelwal. Khandelwal was one of the co-workers with Saraf in ULP Rajasthan in 1979.[27] According to Khandelawal, in most of the universities, experiments are formatted for the determination of physical parameters or the verification of a law. An experiment in this format typically involves the measurement of a specific quantity and based on this, a set of equations are employed to determine some other quantities. Most of the time experimental activity is confined within a specified range allowed by these equations. This turns out to be a serious limitation of the experiments performed in school and college laboratories. Students tend to extrapolate data which runs counter to their real experimental results. Khandelwal seems to suggest that the mismatch between the experimental and theoretical curves creates conflict in the minds of the students. Indeed, the real and comprehensive experimental data in the college laboratory may deviate from the ideal curves or equation provided in theory. Moreover, this format, according to Khandelwal, shuts out the students' mind from the technological and procedural aspects involved in the same experiment. For example, a student may determine charge and mass ratio (e/m) of electrons from an electrostatic deflection experiment and yet remain ignorant about all the nuances of a cathode ray oscilloscope. Khandelwal proposed change in the format of experiment from determination to studying the phenomenon e. g.

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[26] See editorial of Babulal Saraf et al., *Physics through experiments – II* (1979)

[27] Khnadelwal's engagement is reported in *Physics through experiments-II* (1979) and well acknowledged by Babulal Saraf himself.

"study of the deflection of an electron-beam under a transverse electrostatic field". The same experimental activity would enable students to study a number of other relations present in the phenomenon (Khandelwal 1984, 83).

Apparently this would demand re-conceptualization and re-designation of experimental work. Pursuing experiments in this way, according to Khandelwal demands a higher cognitive engagement from the teachers and students, therefore the opportunity to foster greater understanding of phenomenon. Notably, Khandelwal also wrote a book illustrating experiments along these lines. In contrast to convention, experiments in this book are not designed to determine a constant or to verify a law. They are open-ended studies with no instructional prototype for setting the objectives, assembling or designing the apparatus, recording, analyzing and interpreting the data is provided. The intention was to discourage what he calls the malpractice of prefixing the format for conducting experimental activity as is conventionally furnished by the laboratory manuals. Rather emphasis was placed on making experiments an exploratory activity along aforementioned lines.[28] This essentially means that students should be trained in the procedures of scientific investigation i. e. the study of physical phenomenon by using standard laboratory equipment; developing observational skills, performing systematic analysis and interpretation through graphic data and control of errors. Improvisation of the experimental set up was suggested to be an essential step to be taken by the teachers and students when lack of finance constrains the acquisition of new apparatus or devices. In order to make it feasible, he suggested teachers and students invent cost-effective experiments (Khandelwal 1984, 84).[29]

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[28] D. P. Khandelwal, *A Laboratory Manual of Physics for Undergraduate Classes* (New Delhi: Vani Educational Publishers, 1985). The book is a compilation of the experiments devised and improvised by him during his involvement in ULP.

[29] D. P. Khandelwal, "Changing the formats of existing laboratory experiments for better educational value, "In *Proceedings of the International Conference on the Role of Laboratory in Physics Education, Jaipur, India (December 29, 1983 – January 2, 1984),* Eds. S. Lokanathan and N. K. Sharma (New Delhi: UGC and UNESCO, 1984), 83-90.

Kushwaha and Hans (1984) reinforced the aforementioned views of Khnadelwal. Moreover, they highlighted the apparent lack of connection between the experimental process and daily life experiences. Following this line or argument, they claim to devise experimental activities to explore and resolve the physical phenomenon outside classrooms in their ULP work at Punjab University Chandigarh.[30]

Complementary views were offered by Lokanathan--another worker in the Rajasthan ULP. He endorsed the inclusion of historical experiments that created breakthrough in the history of physics in the curriculum. "The Physics laboratory must have the following aims. It must help students to understand basic concepts and how experimental work has played an important role in the development of physical theories and ideas" (Opening remarks by Loknathan and Sharma 1984, i-ii).

A complimentary view was put forward by Joshi and Tillu (1989). What is it that leads to an understanding of physics? And why do several students fail to develop a basic understanding of the framework of physics at the end of their undergraduate and postgraduate courses? These were precisely the questions raised by Joshi and Tillu (1989). Akin to the previous analysis, they identified a lack of adequate training in experimental work as a major lacuna in undergraduate physics education in the country. Contrasting with this view, they also lamented the inadequate theoretical understanding that was an outcome of the inadequate and inappropriate methodology of imparting conceptual and logico-mathematical components of physics. Despite the widespread awareness amongst physics teachers, very little effort had gone into the removal of the second lacunae (Joshi and Tillu 1989, 39).[31]

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[30] U. S. Kushwaha and H. S. Hans, "On Planning Laboratory Activities for Undergraduates," In *Proceedings of the International Conference on the Role of Laboratory in Physics Education, Jaipur, India (December 29, 1983 – January 2, 1984),* Ed. S. Lokanathan and N. K. Sharma (New Delhi: UGC and UNESCO, 1984), *281-283.*

[31] The contrasting view expressed by Joshi and Tillu (1989) when ULP and COSIP programs were already in concluded during late 1970s and early 80s.

What does this imply? Joshi and Tillu appear to contend that learning of physics through experimental activity and the logico-mathmatical component are complementary in building conceptual foundations, and overemphasis on one component does not solve the problem. For instance, the measurement of wavelength, spin angular momentum, observation of fringes in an interferometer or the Zeeman splitting, though a matter of experimental skill, alone cannot help adequate conceptualisation of physics. They contended that in designing an experiment, our thinking process is guided not only by our experimental skill and available facilities but also by mathematical competence and abilities. They ask, when students are assigned the task of designing an experiment in an open-ended manner, do the students get a much better opportunity to learn physics? They contend that the idea of imparting physics concepts qualitatively would be more effective at lower levels of physics instruction wherein the objectives of understanding the applications of physics are relatively modest. At the tertiary level, the logico-mathematical nature of physics becomes a predominant part of physics knowledge and is inseparable from the qualitative aspect of learning physics. For instance, while teaching the diffusion of heat through conduction in a solid, even if teachers mobilized all possible material and apparatus such as different solids of varying shapes, instruments to measure and control temperature and radiation their understanding of the phenomenon of heat conduction would not be complete. On the other hand, when the qualitative approach is integrated with the understanding of the logic-mathematical component, students acquire a far better understanding of the phenomenon (Ibid., 41).

In their view they were not aware of any national programme which attempted to help students shed their intrinsic fear of mathematics in physics. And nobody seemed to have invested efforts in bridging the gap in the mathematical training of physics students, nor had anyone formally advocated the view that a lack of appreciation of physics (or science) to a large extent was a result of the lack of appreciation of the logical and mathematical structure underlying it. According to them, instead of overemphasizing the qualitative (or nonmathematical aspect), educators and syllabus framers at the tertiary level should also make a move in helping students understand the process of mathematisation of physics and therefore evolve a holistic view of physics teaching (Ibid., 39-40).

Summary and Conclusion

The policy document prepared by Srinagar deliberation in June 1970 inaugurated new pathways in science education. Formation of Indian Physics Association (IPA) and launching of the journal of *Physics Education* (PE) set in the renewal of physics education in India of continual basis in 1970. Impact of 'question bank' as examination reform did not figure in the reports produced or follow up activities conducted by any agency. Similarly formation of 'science teaching centres' did not figure in the reports on physics education in the country. 'Voluntary examinations' in +2 and undergraduate physics were launched by IAPT during 1987 and 1988, respectively. The subject will be taken up in next chapters.

Notable work was conducted on experiments from different domains of physics at the University of Rajasthan under ULP. Being prototypical in nature, the replicas of these experiments were sold across colleges and university departments of the country (Kumar and Nigavekar 1994). As a result ULP and COSIP groups working in other parts of the country were introduced and gravitated towards the work of this centre. Subsequently, the centre turned out to be a site for the interaction among physics teachers and researchers across the country (Loknathan and Sharma 1984). Upgradation of ULP Rajasthan as Centre for the Development of Physics Education (CDPE) is significant development. In a way this centre was an expression of the idea of 'Science Teaching Centre' envisaged in Srinagar deliberations. The centre continued the work on reconstruction of experiments and their dissemination to various institutions. It became the site to train teachers in the construction and use of experiments in teaching since then.

Widening the role of experiment emerged as the salient outcome of ULP and COSHIP programs. Babulal Saraf (1978) stressed upon the study of physical phenomena, extracting real empirical data, fitting it with the theoretical equations to build concepts. Khandelwal (1984, 83-90) and Joshi (in Joshi et al. 1999) appear to concur with the view that generation and graphical representation of actual experimental data for a large numbers of experiments lays the foundations of phenomenological experiences required to build concepts.

With the passage of time, experimentation as a methodology of physics teaching appeared to acquire a populist tone and left less space for critical debates on other facets of pedagogy. It was in this context that Joshi and Tillu (1989) pointed out to the lack of attention given to conceptual and logico-mathematical components of pedagogy in India. Though they organized an orientation programme for trainee teachers on the logico-mathematical component, no concrete model of learning has been proposed by them. Instead Joshi (in Joshi et al. 1999) limited himself to the endorsement of Khandelwal's view that generation of physical intuition or qualitative understanding of concepts by students at the introductory level. Loknathan and Sharma (1984) called upon their fraternity to produce historical accounts of the way in which experiment has helped bring about the developments in physics. Work in this regard did not translate in a concrete program like science education research producing new historical material for instructional purpose (see section 2.4 of chapter-II on NOS).

The methodology of physics teaching centered on experimental activity was extended to successive curricular documents like Curriculum Development Centre (CDC) (1989) and UNESCO's Project on the *World View of Physics* (1993-1999). The book entitled *World View of Physics* under UNESCO's project embodies this idea and contains curricular modules with explicit instructional guidelines and illustrations. As this program was designed for the introductory level, perceptual experiences are treated quintessential for understanding of physics concepts. Conceptual development through lectures and tutorials are juxtaposed with the experimental activity. Interestingly the advocates of learning of physics through experimentation, concept formation and logico-mathematical procedures worked together in this programme--D. P. Khandelwal siding experimental work and A. W. Joshi, advocating the conceptual and mathematical facets of physics pedagogy.

According to Kumar and Nigavekar (1994, 22), while satisfactory work is accomplished to renew experimental activity, theoretical component remains still unsatisfactory. More so, it could not make a way into the curricular practice in a substantial manner. Part of the difficulty stems from the inadequate material conditions in schools and colleges. They do not have well equipped laboratories; there is insufficient budget for purchasing and servicing of laboratory equipment. Teachers and students regard theory as the most significant component of the curriculum and laboratory work as a burden but necessary for fulfilling formal requirements.[32]

Hestenes (1987, 2006) offers a way to synthesis pedagogical split apparent in Indian physics perspective. According to him, the traditional organization of physics content around concept-formation and over reliance on its deductive illustration is flawed. While offering 'model-building' as the unit of content organization, he appear to reconcile the experimental activity and logico-mathematical components of physics pedagogy—different positions emphasized by Babulal Saraf or D. P. Khandelwal and A. W. Joshi. Taking mathematical modeling as the core for organizing content, the instructional module claims to reveal the continuity between empirical and theoretical

[32] USA, UK and Canada, the countries with whom Indian contingent deliberated on the nature of problems and plausible resolution of physics education in Srinagar during 1970, have made strides in researching the problems of teaching and learning in physics. It is recently (mentioned earlier) in 2009 and 2011 that a few of the Indian physics faculties are making a modest beginning in this area.

concepts. Generating empirical data from observations and experiments, modeling-making process moves through the mathematisation of experimental data, extraction of theoretical models, to theory building and then back to empirical testing. The Instructional cycle reveals the gaps and tacit assumptions left unaddressed by traditional instruction (Hestenes 1987, 2006/2008; Halloun 2007; Kurki-Suonio 2010). Pedagogical renewal of physics education does not limit to the integration of experiments and quantitative component of theory through modeling. Work on nature of pre-scientific conception and developing framework and material on nature of science (and physics) has also been conducted in science and physics education research world over. Though considered as important component of pedagogical renewal rarely any report is actually produced on the work on nature of science component if any in India. Apparently Indian physics education community has to take another stride forward to match the pedagogical developments worldwide.

Chapter 4

Programs and Policies of Indian Association of Physics Teachers (IAPT)

The chapter takes up the formation, objectives and the major programmes and activities undertaken by the IAPT. Since policies steer the programmes pursued by the association, they are implicitly treated. Attempt to produce relevant textual material for introductory and undergraduate levels, devising and executing the National Standard Examination in Physics (NSEP) and National Graduate Physics Examination (NGPE), conceptualisation and preparatory activities of the formation of the Centre for Scientific Culture (CSC), and the orientation programmes for teachers, form the chapter. Accordingly, the chapter is divided into four sections. Rest of the programmes and activities pursued by the association will be taken up in the chapter 5 and 6.

4.1 Indian Association of Physics Teachers (IAPT): Formative Activities

Spanning around a decade during 1970s, the ULP and COSIP projects provided physics teachers the opportunities to interact among them. This gave rise to the desire to initiate further renewal of physics education in the country. Formation of Indian Association of Physics Teachers was the culmination of this intention.

4.1.1 Formation of the Association

As the University Leadership Programme (ULP) and College Science Improvement Programme (COSIP) reached the end, it became evident that, with a few noted exceptions, the quality of work in most of the places did not turn out as envisaged. However, the exemplary outcome of the programme at Rajasthan University, as well as the concurrent efforts of other ULP and COSIP groups appears to have instilled a sense of confidence in the physics teachers and researchers involved in the projects (Panda 1984; Khandelwal in IAPT 1984, 2). A significant outcome of COSIP and ULP was that the interactions between physics teachers during this period generated an awareness of each other's concerns, ideas and expertise. Amidst this scenario, a section of physics teachers strived to organize themselves as a cohesive group. The attempts to reconstruct the physics curriculum during the ULP and COSIP projects had prepared the ground for physics teachers from different parts of the country to come together for the next round of interactions, though this time, to form their professional community. Hence, it was deemed necessary to further galvanise physics teachers and researchers for the next phase of work on undergraduate physics education in the country. This intention was already voiced in the Jaipur conference in 1983-84 (IAPT 1984, 2-3).[33]

Though the Indian Physics Association (IAP) was around since 1970, it was felt that the mandate of this association was basically research in physics and thus educational aspects need to be addressed separately (Khandelwal 1984, 16; Joshi 1997, 323-327). A move was made to connect with and provide a common platform to those physics teachers and researcher who were earnest enough to take up joint work to resolve the problems of undergraduate physics education in the country. Eventually, under the leadership of D. P. Khandelwal--a retired faculty from Herbert Butler Institute of Technology at Kanpur, the Indian Association of Physics Teachers (IAPT) emerged.

On 1st February, 1984, D. P. Khandelwal wrote to the heads of the physics departments in various Universities and colleges that had run COSIP and ULP programmes as well as other physics teachers spread across the country to get their response to the idea of forming an association of Indian physics teachers. Another letter was sent on 22nd February to physics teachers spread across 20 states and union Territories. As claimed, about 1100 physics teachers responded positively. A local steering committee comprising 10 members

[33] As mentioned in chapter 3, the international conference on the role of laboratory in physics education held at Jaipur, on December, 1983-84 (Dec-29, 1983 to Jan-2, 1984), was the culmination of ULP and COSIP prgrammes and an expression of the emergence of a physics education fraternity in India.

with Indu Prakash, D. P. Khandelwal and V. P. Tayal, the president, convener and treasurer, respectively, was formed at Kanpur on 9th March of that year. The association was named the 'Indian Association of Physics Teachers'. Subsequently the physics teachers from other parts of the country readily joined the association (IAPT 1984, 6-7).

A monthly bulletin was launched to forge communication ties between the members, as well as disseminate news and literature on physics education. The first issue of the bulletin came out on the 19th March, 1984 (IAPT 1984, 6).[34] Since then, it has been serving as the major forum of discussion for the large majority of physics teachers in the country.

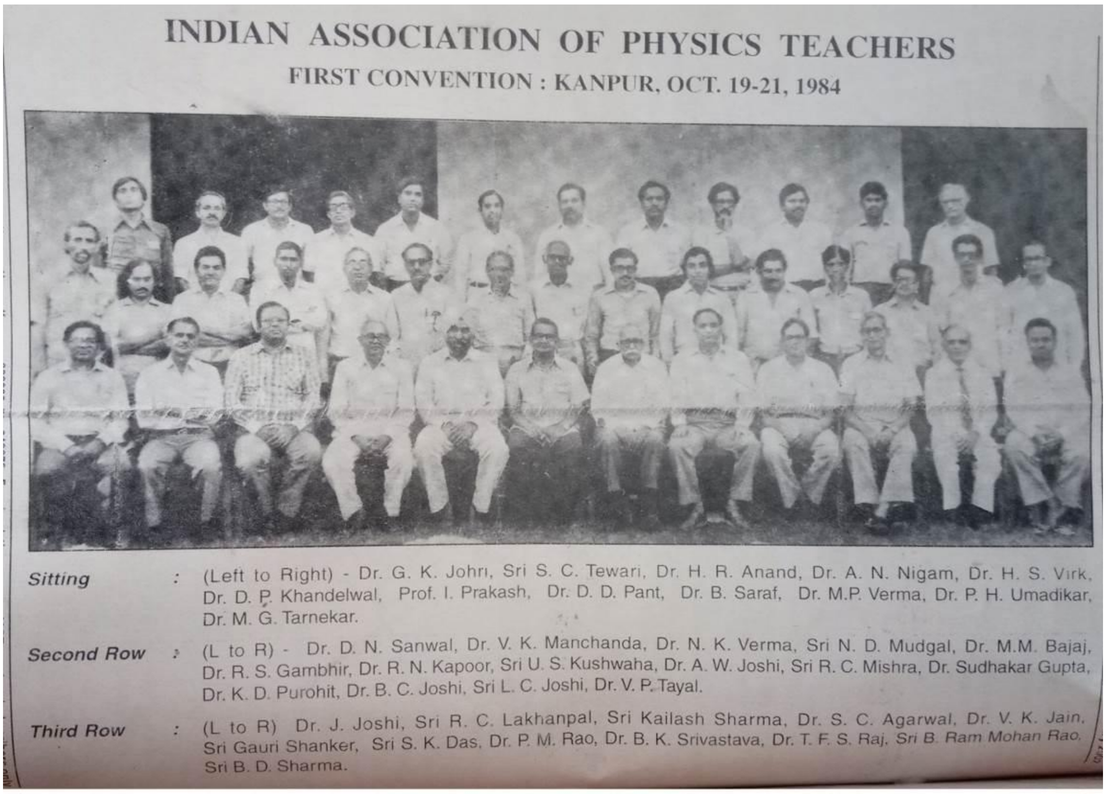

***Figure 4.1 Gathering of IAPT memebrs in the First Annula Convention in Kanpur, Oct, 1984**. Source: Bulletin of the IAPT, Febryary 2002.*

The first National Convention of the association was held at Kanpur from 19th to 21st October, 1984. The Convention marked a major breakthrough in

[34] The bulletin was named as Bulletin of the IAPT.

bringing the community of Indian Physics Teachers to a common platform and witnessed the formulation of the objectives, constitution as well as the formation of the executive committee to enact them. The executive committee comprised of 12 members with Babulal Saraf, P. H. Umadikar and D. P. Khandewal, respectively as the president, vice-president and general secretary of the association (Khandelwal 1984, 20-29).

4.1.2 Objectives and Activities of the Association

The Association sought to evolve a national perspective on physics education in the country. The following objectives and activities were identified by the association at its first annual national convention.

> "OBJECTIVES
> The objectives of IAPT will be to upgrade the level of teaching in physics and related areas at all levels—both inside and outside the educational system—and to pool and mobilise the talents and resources of teachers for it in the national perspective.
> IV ACTIVITES
> The activites of IAPT will include:-
> (a) Preparing high quality teaching material on physics and related areas, like books, monographs, audio visual aids, etc.
> (b) Evaluation and development of laboratory and demonstration equipment and planning of comprehensive lab programmes.
> (c) Holding conferences, seminars, workshops, reorientation programmes etc., for teachers.
> (d) Enhancing public knowledge of and interest in physics and related areas through radio and TV talks, public lectures and exhibitions, museums etc.
> (e) Publishing periodicals devoted to physics teaching on a broad base—for teachers, students and the general public.
> (f) Identifying and giving recognition/awards to varied talents among teachers at different levels.
> (g)Maintaining a pool of information regarding the special talents and interests of its members and providing expert services of IAPT to outside agenecies for purposes such as vetting of books, reviews, translation, evaluation, conduct of apecial programs, etc.
> (h)Coordinating with other national and international bodies having similar objectives, and
> (i) Undertaking such other tasks as may be in conformity with the objectives of IAPT.". [35]

Individually or as a group, the members were expected to contribute to their fullest (Khandelwal 1984, 3). It appears that the bulk of these objectives are the continuation of the recommendation of the Srinagar deliberations pursued

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[35] IAPT, "Indian Association of Physics Teachers: Constitution (As passed by the First Convention on Oct. 20, 1984),"*Bulletin of the IAPT* 1, no. 9 (1984*): 30.*

during ULP and COSHIP projects.[36] Supporting and benefiting from other bodies working in the domain of science and physics education; exposing general public with scientific phenomenon and creating a support system for the teachers are further addition in the objectives.

4.1.3 Model Curricula in Physics Education: IAPT's Perception

In order to chart out a novel path the association had to make a reappraisal of previous attempts of national agencies devoted to the renewal of physics education. According to J. P. Garg (1985), the nature of work undertaken in India so far was general rather than specific in nature. Furthermore, the outcomes were not commensurate with the efforts invested. For instance, the Science Education Centres (SEC) opened by the University Grants Commission, did not succeed in inculcating scientific temper in the society.

To Khandelwal, the State Institute of Science Education (SISE) or its equivalents were working to improve quality of science education. Yet, apart from small bits here and there none of them could come up with a comprehensive and long term programme for reforming science education. Besides, University Leadership Programme (ULP) too, with a few exceptions, could not create a sustained impact. What were the reasons for this state of affair? Most of the ULPs, according to him, did not have a holistic vision to reform physics education. As a result, the material produced could not meet the standards envisaged. Coupled with the inadequate exchange of ideas and interaction among the various ULP groups across different universities, the programme did not lead to create a national perspective. While commenting on the latter developments at the Centre for Development of Physics Education (CDPE), Khandelwal observed that it's functioning in the 1980s, despite the personnel being dedicated to teaching, was not progressive as desired. NCERT as a nodal agency at the national level was expected to lead the initiatives for reforming science education. However, its approach was

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[36] Refer to section '3.1' Srinagar Conference: 1970' in chapter 3.

patchy and confined largely to organising workshops and reviews by the experts working on curricular reconstruction. Summer Institutes (SI) run by NCERT, in his account, too could hardly be productive beyond adding to the knowledge repertoire of the trainees (Khandelwal 1986, 30).

The major lacunae experienced in formulating and implementing a programme for renewing physics education in India, according to Khandelwal, was that any curricular reform group within a university or college was confronted with serious administrative constraints as well as impeded by the conflict of ideas and interests of other curricular groups.[37] In contrast, as Khndelwal saw it, work done in USA and UK was exemplary. In his view, reformed curricular material such as Physical Science Study Committee (PSSC), Nuffield Science, Harvard Project Physics courses at school and Berkeley Physics at the undergraduate level brought about during the 1960s could be seen as examples worth emulating in India.[38] The textbooks and laboratory materials developed in these curricula were the result of intensive and prolonged trials and feedback (Khandelwal 1986, 30, 302; Biyani and Tatakne 1989, 194).

4.2 Unfolding of IAPT's Programmes

As a beginning, the first Annual National Convention of the association recorded the presentation of a large number of papers on the subject (IAPT 1984, 20-29). On the other hand, the headings-"Talent search begins" interspersed through various sections and issues of the bulletin encouraged members to identify and share their experiences and expertise. For instance, the heading, "Radio talk about Lasers" asked the members to deliver an

[37] While highlighting the indifference of the authorities Khandelwal stated that in 1960s NCERT constituted three separate groups for developing a textbook for school physics. Though the aim was to bring about novelty in the content organisation, however the end result turned out to be just a few books on the existing pattern. The group that produced novel materials was not supported during the trials and feedback stages. This group according to him could potentially have produced the material matching in quality with PSSC, Nuffield or Harvard program if not abandoned in midway. Apparently it could not produce the desired results (Khandelwal 1986, 30).

[38] References of the projects are mentioned in section 2.1.1, 2.1.2 and 2.1.3, chapter 2.

expert talk on the 'laser and its application' at All India Radio to educate the general public (IAPT 1984, 1). In particular, P. H. Umanikar, vice president and in-charge of the activity, was asked to establish correspondence with the Center for Mass Communications at Pune and Jamia Millia Islamia regarding TV programmes on similar topics (IAPT 1986, 84-86).

Similarly other members' were asked to write textbooks, monographs, popular articles, develop innovative experiments, take up activities for inculcating scientific culture among laypersons through exhibitions, museums, science shows, deliver public talks and lectures, translate physics education literature into Indian languages and produce slide shows, film strips etc. Those taking charge of a specific activity were to be supported by other members in furthering their work (IAPT 1984, 2, 3, 24, 44).

4.2.1 Production of Textual Material

The production of reading material like textbooks, monographs and periodicals was proposed as a major activity of the association. Proposals were invited from the members to initiate the tasks at the individual and group levels. As part of the protocol, the potential authors were to be provided feed-back from other members of the association. The book when completed was to carry the logo of the IAPT signalling an IAPT publication (IAPT 1984, 33-37).

The writing and translation of popular science books was supposed to be one of the ways of inculcating a 'scientific culture' in Indian society (IAPT 1984, 44).[39] Modalities of group work and the allocation of sub-domains of physics to different writers were developed. For example, 3 to 4 groups were to work on the areas like 'simple harmonic motion', 'Interference of light", 'Electromagnetic induction' etc (Biyani and Tutakne 1989, 195). Two manuscripts--one on 'electricity and magnetism' for undergraduate physics and and other for class XI textbook, were received during 1984 (IAPT 1984,

[39]For example see: IAPT, "Service for the Society, "*Bulletin of the IAPT* April (1984): 2.

37-42).[40] The texts produced were then reviewed. To the dismay of the official in-charge of the activity, proposals were abruptly dropped without ever mentioning the nature of the problem or discord between the authors and the association. Commensurate involvement did not come by from other members. Apparently writing textbooks under the banner of IAPT turned out to be a premature effort (IAPT 1986, 323-325).

As part of its mandate, IAPT also intended to collaborate in writing books with the UGC and NCERT. For instance, in 1985 the association deliberated upon the formulation of a physics syllabus with NCERT (IAPT 1985, 198-205). Its members also participated in the UGC sponsored panel discussion held on March 24, 1985 at the department of physics, Aligarh Muslim University on the improvement of research and teaching of physics in the Universities (IAPT 1985, 98-100). Furthermore, in 1991, IAPT sought grants and co-operation from the Ministry of Human Resources Development (MHRD), UGC and NCERT to initiate work on writing textual material. These efforts hardly resulted in any conclusive outcomes. Though earnest in partnering the development of educational material in physics, the IAPT seemed to be out of tune with NCERT. In IAPT's view, NCERT often assigned the task of writing textbooks to a team dominated and directed by researchers in the field and saw this as a flawed initiative (Khandelwal 1991, 292). Latter on Rajesh Popli equated this with the aircraft being flown by top aeronautical researchers and not by professional pilots. According to him most of these researchers can communicate the subject only at the level of the researcher. Besides knowledge of the subject, the prime requirement for textbook-writing was supposed to be the ability to communicate with children of different age-groups and weed out gross errors creeping in afterwards (Popli 1999).

As a result, the executive committee of the association decided that only full-time groups working for about two years or so with extensive field trials

[40] SurajPrakash and O. P Khandelwal were mentioned as the authors of class XI textbook. The name of the authors of undergraduate book was not mentioned.

could develop trial-based text-books, experiments and supplementary reading materials etc. This resonated with the experiences of the major institutions developing educational materials in the West; part-time engagement even from the top academicians would only scratch or scan the surface (IAPT 1991, 154-155). Eventually, the association expressed its inability in working out a collaborative project on physics education with MHRD or UGC.

Unlike textual material, writing a series of supplementary books useful for undergraduate physics students and teachers was successfully set into motion. The supplementary readers were supposed to be a collection of around 15-20 articles on physics. The idea behind the programme was that since review articles published in physics journals were too technical for college teachers and students in India, it needed to be made comprehensible and accessible to a wider physics readership (Saraf 1984, 23-24; IAPT 1984, 44;).

Rather than detail and rigour, emphasis was to be placed on the concepts and applications as per the needs of common teachers and students. Exposing this readership to the advancements in the theoretical, experimental and technological domains of the discipline was an important objective of the project. The supplementary material was also meant to cater to the needs of researchers keen to update themselves with the latest research. These readers sought to enhance the knowledge horizons of inquisitive students and teachers. The series of publications was labelled *Horizon of Physics*. Additionally, these books were intended to serve as reading material for M. Phil. courses and in the orientation programmes for teachers–-commensurate with both national and international standards (Joshi and Hans 1989).

Having formulated the program the association invited its members to contribute to the series. While some of them offered to write articles, a few others agreed to review and edit the articles so produced. As a customary gesture, the authors were to be remunerated for their contributions (IAPT 1984, 44). Though initially hesitant about the saleability of these books, Wiley Eastern offered to publish them (Joshi and Hans 1989).[41]

The first volume of the *Horizon of Physics* appeared in 1989. The volume included articles from diverse sub-domains of physics. As such not only was it well-received by the members but also promoted a feeling of solidarity among them. The first volume had articles on the special and general theories of relativity; development of quantum mechanics; modern physics, research techniques such as X-rays and Mossbauer spectroscopy, furnishing ideas related to solids, atoms, and nuclei; scattering under a generalized coulomb potential, in ion-ion interactions; nuclear physics and high energy particles physics; solar system, the composition and structure of universe and its study by radio astronomy etc. Some articles such as 'Faraday's laws' were intended to address basic concepts. Posing some essential questions at first and then leading to the foundations of the subject, was claimed to be the principle guiding the exposition of the content. Beginning at the undergraduate level, most of the articles extended to recently developing areas of physics. X-rays and synchrotron radiation were described in the articles on X-rays and hypothesis of six quarks (including charm, beauty and truth quarks) and electron-positron collision experiments were treated under particle physics. The research topics on cosmology (such as black-holes, quasars, pulsars, the missing neutrino problem, dark matter) were dealt in the articles on astrophysics and relativity.

Having brought out the first volume of *Horizon of Physics* successfully, the association was encouraged to bring out next two volumes on a regular basis (Nath in preface of Nath and Joshi 1996). Apparently, following the comments and suggestions received on the first volume the subsequent volumes were expected to incorporate them. As per the schedule, the second volume was

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[41] A. W. Joshi and H. S. Hans, eds., *Horizons of Physics-1: Indian Association of Physics Teachers* (New Delhi: Wiley Eastern, 1989)

expected to come out in 1991. But its publication was delayed till 1996.[42] The second volume of *Horizon of Physics* consisted of articles on both theoretical and experimental physics e. g. geometric phase, randomness and chaos and high-temperature superconductivity. As a matter of policy, emphasis was placed on the basic concepts while covering the topics like 'search for unification in physics', nature of time and nuclear forces, basic crystal structure and methods for its analysis, etc. Looking at the growing importance of research in materials science, the publication offered students' to develop insight into the physics of diamonds, the role of neutrons in the study of solids as well as the techniques of X-ray inelastic scattering. The articles like 'symmetries in particle physics' and 'Fourier transforms spectroscopy' were supposed to cater to the needs of readers preferring theoretical abstraction and applications.

The third volume of *Horizons of Physics* series was entitled-"Physics of Particles, Nuclei and Materials: recent trends" and was released in 2002. The book consists of three parts, namely, high energy particle physics, intermediate and low energy (nuclear) physics and the physics of molecular and solid state materials.[43] As a matter of policy, the contributing authors were asked to write comprehensive reviews of their respective fields of expertise, commencing with a detailed introduction to the present status of the research. In contrast to the coverage of articles in the earlier volumes that meticulously covered topics from diverse areas in physics, the selection of articles was now based on authors' personal preferences (Srinivasan 2002). Rather than paying attention to the needs of undergraduate teachers and students, the new volume exclusively focused on recent trends in physics research. The volume was called *New Horizons of Physics*.

The major shift towards research based articles signals the departure from IAPT's initial mandate to limit and focus its work within the boundaries of

[42] Narendera Nath and A. W. Joshi, eds., *Horizon of Physics–II* (New Delhi: New Age, 1996)

[43] Raj Kumar Gupta, ed., *Physics of Particles, Nuclei and Material: recent Trends* (New Delhi: Narosa Publishing House, 2002).

physics education as D. P. Khandelwal, had repeatedly highlighted.[44] How did these books and articles differ from similar literature available in other published books and journal articles? How were they received by the intended readers? No follow up report and review or reappraisal was conducted by IAPT in this regard.

4.2.2 Model Examinations for Secondary and Undergraduate Physics

A cursory look at the pattern of examinations suggests a strong linkage between what was taught in the classroom and how it was tested in the examinations. When the highly acclaimed goals of physics teaching vis-a-vis internalization of concepts, solving genuine problems and attaining proficiency in carrying out experimental work is superseded by the delivery of information, it is but natural to assume that the examinations would comprise memory based questions, requiring students to reproduce facts, derivations and solve routinized numerical problems. Disproportionately high marks awarded for the reproduction of facts further reinforces a pedagogical practice emphasizing rote learning in classrooms. Even if genuine attempts are made by individual teachers to break free of this practice, the inertia ridden system offers resistance to counteract it (Khandelwal 1991, 146-151). Though exaggerated, Virk and Kushwaha go so far to suggest that these examinations motivate physics teachers to teach what they teach (Virk 2000, 232; Kushwaha 2007, 175).[45]

If the examination formats, emphasizing factual or cookbook knowledge, shape the teaching and learning in the classroom, would restructuring the content of the examination in favor of concepts, genuine problem solving and experimental knowledge and skills help reverse the trend? Having asked this question, the IAPT, in 1986 and 1987, set out to develop and execute such a

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[44] For example, H. S. Hans, the second presidents of IAPT, advocated that IAPT should include M. Sc. and M.Phil. and research in the domain of its activities (Hans 1988, 2, 24).

[45] H. S. Virk was the president of the IAPT (2004-2006) and Kushwaha has held key positions, such as in-charge of NSEP (1987-1989) and editor of the *Bulletin of the IAPT* from 2003 onwards. Kushwaha, along with H. S. Hans, played a key role in ULP under Punjab University.

model of national examinations for senior secondary and undergraduate physics, respectively (IAPT, 1986, 84-86). The examinations were termed as National Standard Examination in Physics (NSEP) and National Graduate Physics Examination (NGPE), respectively.[46]

4.2.2.1 National Standard Examinations in Physics (NSEP)

As the name suggests NSEP was intended to serve as the benchmark of secondary physics examination in India. Besides the prospect of bringing to centre stage the teaching of concepts and problem solving, the examination was supposed to have other ramifications (Thakur 1989, 221). While making an earnest appeal to the IAPT fraternity Khandelwal (1991) wrote: "NSEP should not become just an "examination" for evaluation. Let us make it a vehicle for self-education and a conscious drive for the improvement of physics education" (146). In particular, it was presumed that having confronted conceptual and problem solving questions in these examinations, students would bring these to the notice of their teachers', who in turn would respond with a sense of responsibility. In case, teachers were unable to solve the questions, they would have to raise their expertise by revisiting the subject at the appropriate level and come up with a deeper understanding of concepts and develop the ability to solve physics problems in novel situations. Eventually teachers would adapt their teaching methods to aid students to gain a deeper and thorough understanding of the subject. Pressing teachers to bring about desirable changes in their methodology of teaching physics could directly or indirectly induce a new trend in textbook writing (IAPT 1986, 84-86; Sahani 1989, 217; Thakur 1989, 221).

To construct a model NSEP, a competition was proposed that balanced factual, conceptual, problem solving and experimental questions. Entries were invited from teachers, researchers as well as students—whoever had an interest in collecting or developing questions based upon the aforementioned

[46] Interestingly, as mentioned earlier (chapter 3, paragraph 2, page 68) conducting a voluntary examination at the national level for undergraduate physics students was one of the recommendations of the Srinagar Conference (1970).

criterion. To encourage the participation, the best paper setters were to be felicitated with awards and certificates (IAPT 1987, 194; Srinivasan 1992, 95).[47] The first model test paper for NSEP was finalised by placing emphasis on testing, understanding, interpretation, inferring from graphs and diagrams, problem solving, estimation of errors and identification of misconceptions etc (Khandelwal 1991, 146-151).[48] Apparently the goal was to depart from 'fact-based' question papers prevailing in the school physics and college physics examinations.[49]

Once the model NSEP was ready, a nationwide preparation for holding the examination was undertaken from July, 1986. IAPT members, in large numbers, voluntarily offered their services for executing the program. Communication channels were established through IAPT's bulletin and the network of contacts with schools and other educational institutions spread across the country. Volunteers were asked to spread the word about the examination and help enroll as many students as possible from all across the country. In some cases, it was claimed that Indian schools in other countries were also approached to enroll and register at NSEP centres (Khandelwal 1990, 319-320).

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[47] As regards the format, 'objective', 'short answer' and 'long answer' type questions constituted the test papers. Format for the year 1988, 2001 and 2010 for NSEP and NGPE is shown below.

NSEP—88: Part A---60 question testing factual and conceptual understanding, multiple choice type, 3 marks each; Part B—8 questions testing problem solving ability, 15 marks each. Source: *Bulletin of the IAPT* 5, no. 2 (1988): 63-69.

NGPE—88: Part A—60 questions testing factual and conceptual understanding, short answer type, 3 marks each; Part B—5 questions testing problem solving ability, long answer type, 12 marks each. Source: *Bulletin of the IAPT* 5, no. 2 (1988): 52-62.

NSEP-(2000-01): Part A-1=40 questions testing factual and conceptual understanding, multiple choice type, 4.5 marks each; Part A-2=10 questions testing conceptual understanding and problem solving ability, short answer type, 6 marks each; Part B=05 questions testing problem solving ability, long answer type, 120 marks. Source: *Bulletin of the IAPT* May (2001):137-144.

NGPE—2010: Part A—25 questions testing conceptual understanding, multiple choice types, Part B—10 questions testing conceptual understanding and problem solving ability, short answer type, Part P—10 questions testing problem solving ability. Source: *Bulletin of the IAPT* Sept (2010): 287.

[48] The practice of preparing model examination by holding competition among the members of the association was consolidated in next few years.

[49] Refer to Appendix 2: NSEP 2006-07

The examination was held on the 25th of the January, 1987 (last Saturday of January).[50] With a view to enable students to draw benefit of discussing questions with their teachers, the timing of the examination was deliberately placed in between academic sessions. However, since the examination was not linked with admission or scholarship opportunities for the students, there was skepticism about the popularization of the examination. Teachers implementing the programme in the field were asked to invest extra effort in generating awareness about its importance and seek the help of teachers in schools to motivate their students enroll in the examination (Biyani and Tarnekar 1989).[51] Since the effort was voluntary, organizers were offered a nominal remuneration (Khandelwal 1990, 319-320)

While introducing the NSEP in 1987, IAPT aimed to enroll around 5000 students from all over India. However, in the first year itself the participation was overwhelming. More than 20,000 candidates from all over India enrolled for the examination. About 30,000 students enrolled for the next NSEP in 1988 (Khandelwal 1991). The success with the examination encouraged the IAPT members and the event was seen as a landmark in its brief history. Over the years there has been a steady rise in the enrollment of the students from all the corners of the country (Srinivasan 1992, 95).[52] As claimed, students participated actively in the examinations and discussed difficult questions among themselves and with their teachers. Teachers on their part positively responded to inquiries from the students (Biyani and Tarnekar 1989). Babu Lal Saraf suggested that a detailed analysis of the answer sheets of examinees should be utilised as data to obtain information about the errors committed by students on concepts and problem solving. An institutional and region-

[50] Though examination was scheduled to be held on the last Sunday of the month, may be 26th being the independence day of India, it was preponed on Saturday.
[51] A fee of Rs. 5 for NSEP-1987, Rs. 10 for NGPE-1988 was charged per candidate. Source: *Bulletin of IAPT* (1988): 170-173. In 2011 this rose to Rs. 50 for NSEP and Rs. 75 for NGPE, respectively. Source: *Bulletin of IAPT* (2010): 287.
[52] 37,100 candidates enrolled for the NSEP (physics only) and 93,455 enrolled for the physics, chemistry, biology, astro (Jr) an astro (Sr) examination in 2009. Source: Bulletin of IAPT (2010): 71-82.

wise analysis of the errors was suggested to serve as inputs for the next phase of the activity (IAPT 1987, 340). Though a few analysis were conducted (for instance Murthy and Khandelwal 1990, 15-17; 1990, 18-19), the analysis never reached a conclusive end. At best the IAPT ended up providing printed solutions of the NSEP to the examinees (IAPT 1989, 141). In 1991, a questionnaire was also added to the NSEP seeking feedback from students and teachers to improve it further (Khandelwal 1991, 146-151).

4.2.2.2 National Graduate Physics Examination (NGPE)

Following the successful introduction of NSEP, IAPT launched National Graduate Physics Examination (NGPE)--similar examinations for undergraduate physics students on 31st January, 1988 (IAPT 1988, 124). As was the case with the NSEP, the score obtained by the students in these examinations was supposed to provide a measure of the degree of assimilation of facts, conceptual understanding, and problem solving abilities. According to Srinivasan (2003, 101)—the coordinator of the NGPE, the examination was intended to give students feedback on where they stand in relation to other students in the country. The objective was to raise the level of physics learning. Conducting the NGEP was relatively less cumbersome since the organizational structure was already in place. The conceptualisation and execution of the examination was on similar lines. Most of the teachers were from the colleges and by putting in some extra effort were supported by the host institutions in conducting the examination. The outcome of this examination was no different from the NSEP.

4.2.2.3 Experimental Parts of NSEP and NGPE

All entrance examinations, whether for undergraduate or post graduate courses, across the country, tested the conceptual and problem solving abilities in physics. None of these examinations had a provision for testing their experimental knowledge and skills. Therefore, as Khandelwal (1991, 146-151) argued, when laboratory activity has already been pushed to the margins of the schools and college curriculum, its exclusion in entrance examinations has further degraded the role and importance of physics experiments. As comprehensive overhauling of physics laboratory work became a major objective for the IAPT, testing of knowledge and skills relating experiments to NSEP and NGPE examinations was considered vital. The NSEP and NGPE examinations had already sought to catalyze a shift from the testing of facts and derivations to that of concepts and solving non-routinised problems. The inclusion of the laboratory component was expected to complete the initiative. It was hoped that IAPT's example would be followed by other examining bodies. As Khandelwal put it: "As things in India stand if you introduce such evaluation in the admission tests like JEE or scholarship tests like National Science Talent Search from, say, 1994, you may be sure that right from July 1993 there will be pressures on schools and teachers and the coaching institutes to strengthen the base of their science laboratories. In fact the coaching institutes may be the first to establish real good laboratories and workshops" (1992, 77).

The addition of the laboratory component to NSEP and NGPE examinations was considered significant on two counts. Firstly, they could create a demand for better laboratory training; secondly, the selection process for future professionals could be more rational and not biased in favor of theory. Furthermore, it was thought teachers and students in schools and colleges would begin pursuing experimental work with due seriousness (Khandelwal 1993, 176-179). Consequently, IAPT incorporated experimental skills in NSEP in 1992 and later NGPE in 1993. These examinations were termed as NSEP Part-C and NGPE Part-C, respectively.

In order to conduct examinations, it was necessary to identify the repertoire of valid experimental skills students required at this level and design corresponding experimental activities and introducing them into the curriculum (Khandelwal 1992, 77-78).[53] The organization of the examination required the dexterity in manual work, managerial skills and financial outlays

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[53] See the appendix 3 for NSEP-Part (C), 1993 and 1995

(Khandelwal 1991, 146-151). Lack of resources and skilled manpower posed difficulties in holding the examinations. In order to sort out the problem, NCERT was approached by the association. NCERT readily joined hands with IAPT in designing and holding the experimental part of the NSEP in 1992. It was a heartening experience for IAPT members that NCERT took a supportive stand in extending facilities at venues, designing experimental items in its workshops as well as playing an active role in the organising related activities. As per schedule, the first such examination was held at the Regional College of Education, Bhopal from June 4 and 6, 1992 (Srinivasan 1992, 156; IAPT 1992, 215).

In 1993, there was extensive cooperation between IAPT and NCERT in organizing the evaluation of NSEP Part-C. The items for testing experimental skills were critically discussed among the representatives of IAPT and NCERT. The apparatus and equipment for the examination were fabricated at NCERT workshops in Delhi. The evaluation of experimental skills was conducted on May 28 at NCERT and its supported institutions i. e. Regional College of Education at Bhopal, Bhubaneswar and Mysore, and NCERT Delhi itself. With the enhanced support from NCERT in 1993, the number of candidates examined increased from one to two hundred (IAPT 1993, 249: Khandelwal 1993, 220).

Having made significant strides in two years, the collaboration between IAPT and NCERT proved to be short lived. From 1994 onwards NCERT did not continue collaboration in conducting the examination with IAPT in (IAPT 1995, 215). The same framework for the examination testing experimental skills was adapted from 1994 to 1995: i. e. 20 questions of 3 marks each, 5 questions of 12 minutes each and 2 questions of 30 minutes each, remained the format of the examination (see the appendix 3).

Following NSEP Part-C, the evaluation of experimental skills for NGPE commenced on May 28, 1993. Unlike the collaboration with NCERT in organizing NSEP Part-C, IAPT had to conduct NGPE-Part-C on its own. A group of IAPT members from Mumbai took responsibility for holding the NGPE Part-C (IAPT 1993, 249).[54] Some of the local colleges furnished the equipment needed for the examination. In contrast to NSEP, the top 2% of meritorious students from NGPE were examined for the experimental part (Khandelwal 1993, 324).

Evidently, from their inception the NSEP and NGPE examinations were not linked to any admission or scholarships. Khandelwal, then General Secretary of IAPT, stressed that conducting these examinations was not so much about identifying and rewarding the 'talented' but to enable students and teachers from all across the country to have an experience of a 'model examination' offering a challenge to their conceptual and problem solving abilities (Khandelwal 1991, 146-151). However, the demands of increasing student participation led IAPT to commence ranking examinees and awarding certificates of merit to the students. After examining the top 1% from NSEP and 2% from NGPE for their experimental skills, the top (both in theory and experiments) 25 candidates were awarded merit certificates (Khandelwal 1991). Ceremony is an annual process since then. The students topping the examinations were encouraged towards taking up carriers in physics research from the beginning of the examination (Maity 1989). Satyendra Nath Bose Centre for Basic Sciences (SNBCBS) offered admission to the top 5 to 10 candidates of the NGPE into its M.Sc. Programme (IAPT 2003, 3).[55]

Without NCERT support, IAPT continued to conduct the part—C of NSEP and NGPE examinations on its own for two years and had to discontinue it from the year 1996. After a long gap of 6 years the NGEP and NSEP were revived in 2001 and 2002, respectively. With the establishment of the Regional Councils of IAPT, the major organisational responsibility for conducting

[54] P. H. Umadikar, P. M. Dharkar, M. Kumar, S. R. Kaulgud and N. M. Savardkar.
[55] Direct absorption of the meritorious candidates by SNBCBS is intact today.

examinations was shared by them.[56] For instance, in 2001, the regional Council 10A, Kolkata, entrusted S. C. Samanta from Midinapore College with the responsibility of holding NGPE Part-C examination. The top twenty-five students, based on their performance in the theory examination, were invited to take part in the examination on 26-27th May 1993. Subsequently, 5 top rankers (combining theory and practical examinations), were awarded with NGPE gold medals (Samanta 2001, 350-351). The NSEP Part-C examination was held at Anveshika, SGM Inter College Indira Nagar-Kanpur on December 29, 2002. The local as well as national NSEP toppers were called for the examination (Kapoor 2003, 61-64, 65).

4.2.2.4 Coordination with other Teachers' Associations

In 1987, the then president of India, Gyani Zail Singh presided over the first awards ceremony for the top rank holders of NSEP held at the IAPT's Annual National Convention at Chandigarh on July 14. Appreciating the IAPT's initiatives, he suggested similar voluntary examinations in chemistry, biology and mathematics be organized (IAPT 1987, 175-183). This would have put extra pressure on IAPT's organizational capacities. Two options were open. One was to have IAPT and its counterparts in chemistry, biology and mathematics as separate organizations and then have an apex body

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[56] IAPT from the beginning had mandate for national character in view. However, keeping in view the issue of better governance, it went for having regional committees. Consequently, six (6) regional committees were formed by the association during the year 1993. Namely, these were, North West region comprising of Delhi, Haryana, Himachal Pradesh, Punjab and Jammu Kashmir; North Region comprising of Utter Pradesh and Bihar; West Region--Rajasthan, Gujarat, Maharashtra and Goa; Central Region--Madhya Pradesh and Andhra Pradesh; Southern Region--Karnataka, Tamil Nadu, Kerala, Pondicherry; and Eastern Region--Orissa, West Bengal, Assam, Eastern states and Sikkim. Since their formation, regional committees have steadily been contributing for the growth of the association, for instance adding more members and increase the enrolment for NSEP and NGPE etc (IAPT 1993, 142). Latter in 1995, regional committees were renamed as Councils and expanded to 12: (1) Delhi and Haryana, (2) Punjab, Chandigarh, Himachal Pradesh, Jammu and Kashmir, (3) Utter Pradesh, (4) Rajasthan, Gujarat, Daman and Diu, (5) Maharashtra and Goa, (6) Madhya Pradesh, (7) Andhra Pradesh, (8) Karnataka and Kerala, (9) Tamil Nadu and Pondicherry, (10) West Bengal, Orissa, Andaman and Nicobar Island, Sikkim, (11) Assam, Arunachal, Meghalaya, Manipur, Tripura, Nagaland, Mizoram and (12) Bihar (Umadikar 1995, 123).
Currently there are 20 Regional Councils and West Bengal along with Andaman and Nicobar Islands and Sikkim being the 16th. See:
http://www.indapt.org/index.php/councils

coordinating them. The other was, while keeping the task under each discipline separate, expand the sphere of activities of the IAPT to all science disciplines and rename the IAPT as the Indian Association of Science Teachers (IAST). With well-developed infrastructural facilities, IAPT reportedly offered to conduct the voluntary Standard Examination in chemistry and mathematics in 1994 (IAPT 1994, 29, 61). Further plans did not materialize. The Association of Mathematics Teachers of India (AMTI) was functional since 1965 and like IAPT, had a substantial pool of manpower and resources.[57] As a matter of fact, IAPT and AMTI remained separate bodies with limited cooperation. For example, both these associations of teachers offered to provide the secretarial assistance for establishing the Association of Chemistry Teachers (ACT), in the year 2000.[58]

4.2.2.5 NSEP: A Preparatory Stage for Indian National Physics Olympiad

Working with the educational agencies in ushering debates and work on alternatively better examinations in school and college physics, has been one of the objectives of the association. In fact NCERT in the first two years (1993 and 1994), had coordinated Part-C of the examination. Godbole (1992) suggested that the association persuade the examination bodies at state and central levels to incorporate the testing of experimental skills. Despite desiring the co-operation of these examining bodies, IAPT could not come closer to such a possibility.

Working towards India's participation in International Physics Olympiad was another possibility considered by IAPT. The International Physics Olympiad (INPO) commenced in 1967.[59] It is said to be a unique educational event designed to discover, encourage and challenge exceptionally gifted students, at the stage of completing schooling (Singh 2007). Organising preparatory examination for India's participation in the International Physics Olympiad

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57 https://www.amtionline.com/

58 http://www.associationofchemistryteachers.org/

59 Refer to Waldemar Gorzkowski, "International Physics Olympiad (IPHO): Their History, Structure and Future, "*AAPPS Bulletin* 17, no. 3 (2007): 2-11.

had long been deliberated upon by the IAPT (Srinivasan 1995, 88). It was proposed that around 25 to 50 (preferably 35) top rankers of NSEP part A, B and C could be trained for participation in the International Physics Olympiad (Ratna and Prakash 1995, 197). Possibly it was due to lack of infrastructural facilities or dampening of the spirit to take it forward following the expiry of D. P. Khandelwal in 1996 or some other reason, the IAPT could not initiate activities towards this end.

As a matter of fact India's preparation for International Physics Olympiad (INPO) in 1998 was inaugurated at the Homi Bhaba Centre for Science Education (HBCSE). Since then, the HBCSE has been acting as the nodal agency for the selection and training of students for the INPO. HBCSE sought the cooperation of IAPT in organising the Indian National Physics Olympiad (INPhOPiad)—the preparatory program for India's participation in the International Physics Olympiad. As a partner in organising the preliminary part of the examination, IAPT's identified 200 meritorious students through the NSEP examinations. In fact NSEP acts a screening test for selecting the potential trainees for Indian National Physics Olympiad (Chattopadhyaya 1997, 310, 341-342).

IAPT and National Steering Committee for Physics Olympiad (set up by the Board of Research in Nuclear Science, Department of Atomic Energy) jointly organised the first countrywide Indian National Physics Olympiad (INPhO) on May 8-9, 1998 for 200 students selected on the bases on NSEP held on Dec 21, 1997. Out of this lot 35 candidates were awarded IAPT NSEP-INPhO Gold Medals at HBCSE (TFIR). These 35 candidates were then provided a 4 week intensive training camp in problems and experiments from May 18 to June 12, 1998 (Kumar 1998, 220-221). In addition, a few direct nominations were also invited for this examination (Chattopadhyaya 1998). Eventually 5 top students represented India in International Physics Olympiad during 2 -10th July, 1998 at Reykjavik, Iceland (Kumar 1998, 241-242).

A formal beginning was made for holding the National Standard Examination in Chemistry (NSEC) and Biology (NSEB) from December, 1999 as a prelude to the holding of the Indian National Chemistry Olympiad (INChOpiad) and Indian National Biology Olympiad (INBiOpiad). While IAPT helped conduct NSEC and NSEB tests, setting the question papers and evaluating the answer scripts is the prerogative of HBCSE. Being its own examination, IAPT continued to set the question papers and evaluate NSEP answers scripts till the selection of final top 200 students for the Indian National Physics Olympiad (Kumar 1999, 191).

Since its inception in 1998, the Indian National Physics Olympiad has been playing a critical role in the country's Olympiad program. With the involvement of government of India through HBCSE, extensive publicity through newspapers, printed circulars, radio and TV, magazine articles, began to be given to NSEP, NSEC and NSEB. Separate funds were earmarked for publicity and information within the general budget of the Olympiad program (Ibid.).

4.2.3 Conceptualising Centre for Scientific Culture (CSC)

IAPT's attempts to methodologically and materially renovate physics experimental activity was not limited to school and college settings. It was also meant to educate laypeople. In fact, the objectives formulated by the association included the education of the general public in science and scientific method.[60] With these objectives in view, D. P. Khandelwal formulated the idea of 'centre for scientific culture'--a centre having the features of both a science museum and a working science laboratory.[61]

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[60] Refer to the IAPT's objectives in the opening sections of the chapter.

[61] D. P. Khandelwal, "Outline of a Science Centre, "*Bulletin of the IAPT* 3, no. 4 (1986): 115-120.

D. P. Khandelwal, "Centre for Science Culture—A Blueprint, "*Bulletin of the IAPT* 5, no. 1 (1988): 5-11.

D. P. Khandelwal, "Development of Centres for Scientific Culture: Proposals Invited, "*Bulletin of the IAPT* 1, no. 4-5 (1991): 160.

D. P. Khandelwal, "Development of Centre for Scientific Culture in the Society and Stage Science Shows (Project submitted to the Ministry of Human Resource Development), "*Bulletin of the IAPT* 9, no. 4-5 (1991):130-138.

According to Khandelwal, science museums by way of demonstration experiments aim to illustrate scientific phenomenon to the general public. Though an important objective in itself, generally, their impact remains limited to the satisfaction of curiosity and entertainment of visitors. Science museums that are not equipped with the facilities to help visitors perform experiments actively do not inculcate scientific outlook in them. Moreover, items displayed at Indian science museums do not keep pace with technological developments. The invariably high cost of the instruments in science museum adds up the problem (Khandelwal 1985, 23; Khandelwal 1986, 115).[62] Rather than observing the demonstrations, Khandelwal proposed that visitors need to be provided facilities to carry out experiments by taking measurements and interpreting physical quantities. Put simply, visitors need to be allowed to conduct experiments the way students do in school and college laboratories. Hence, appropriate adaptations of the school and college science experiments could be made available to the general public. The science museum so upgraded could be visualised as the Centre for Scientific Culture (CSC) (Khandelwal 1988, 7-8; Khandelwal 1991, 130-131). Apparently Khandelwal's views seem to be limited by resources and institutions of his time. There are sciences museums that help visitors perform experiments actively are obviously in the league of the CSC envisaged (Panda and Mohanty 2010).[63]

On the other hand, CSC could be made a repository of a wide range of working experiments for school and college students and teachers. Students, teachers and technicians having the expertise and seeking facilities for devising concrete artefacts, could be provided with necessary support and guidance at the CSC. Teachers would be the principal actors in the development and organisation of CSC. They would be presenting familiar science experiments, gadgets and games before the general public. In return,

[62] Generally the apparatus and equipment placed at science museum is macro versions of those at school and college laboratories.

[63] Jayanarayan Panda and Bikash Ranjan Mohanty, "Adding Fizz to Science: Changing Role of Science Museums and Science Centres," *Science Reporter*, February (2010): 8-13.

teachers' were supposed to benefit from their involvement in CSC's activities by enhancing their expertise to conceive and design demonstrations and experiments with an added degree of sophistication. The questions and suggestions offered by the participant visitors were supposed to be the feedback provided to teachers in further refining experimental activities (Khandelwal 1988, 6-7; Khandelwal 1991, 131-133).

Why should laypersons be drawn to Centre for Scientific Culture? Khandelwal seems to have the conviction that as human beings we have the curiosity and urge to understand natural phenomenon. This can be tapped, at least in part, and be directed towards scientific activities. For instance, in his view, it would interest laypersons to see for themselves that the period of a pendulum does not vary with the amplitude and mass, or even how the loop length in Melde's experiment varies with the load, or how the current in a wire (for instance, a filament in a bulb) varies with the number of batteries connected across and the way they are connected to it. Thus well designed experiments can unambiguously demonstrate a physical phenomenon and go a long way in generating further curiosities and scientific outlook amongst laypersons. With such an understanding, visitors would naturally be drawn to the CSC. Rather than over playing the surprise element, experiments should be employed to demystify the science and physics (Khandelwal 1988, 7-8; Khadelwal 1991, 130-131).

Unlike science museums, CSC would be conceptualised and run by schools, colleges and professional bodies. The teachers and students from colleges and schools need to take the charge of formulating, designing and running its activities. An open invitation for competitive entries from teachers, students or any person having the potential for designing innovative experiments need to be invited to participate in CSC activities. Besides static and working experimental set-ups, CSC would house other educational material such as film loops, audio-visual aids, lectures, etc. Initially experiments and related material would be drawn from physics and applied areas like electronics, communication, geophysics, biophysics, environment, energy resources etc., and then gradually add up similar items from other science disciplines (Khandelwal 1991, 137).

The ‘stage science show’ (SSS) was conceived as the mode to display and present experiments to the general public. To begin with, stage science shows were supposed to be `low cost' activity. By devising more cost-effective and communicative strategies, intensive activities were planned for rural areas. With flexible logistic support, these shows were to be organised on a weekly basis. In the course of time, CSC would develop an extension wing to organise ‘stage science shows’ in the surrounding rural areas. Local dialects were to be used as the medium of communication in small towns (Khandelwal 1991, 132).

Financially, support for setting up the CSC was proposed to be generated from patrons or donors sympathising with the cause. Like music, magic, dance, drama etc stage science shows had to be paid shows and therefore self-sustaining in character. IAPT was supposed to act as a nodal agency to promote these activities. Without drawing remuneration or funds for its services, as a voluntary association, it would extend its services in the selection of employees, development and evaluation of the performances or demonstrations, and in coordinating the involvement of other agencies. As envisaged, the sole interest of IAPT in the Centre for Scientific Culture was to develop resources and procedures for the advancement of Science education (Khandelwal 1991, 135-136).

An inbuilt appraisal mechanism was proposed for the continuous evaluation of CSC activities. The director of the CSC, in particular, would be employed on contract and only the staffs that make worthy contributions would be asked to stay. This was supposed to make CSC result-oriented (Khandelwal 1991, 137).

Finally, model CSC once established would serve as a prototype for its replication in other parts of the country. Rather than being simply a clone of the prototypical CSC, each of the new centres was envisioned to have its own distinctive character (Khandelwal 1986; Khandelwal 1988, 5)

4.2.3.1 Initiatives for the Establishment of CSCs

To initiate the work on Center for Scientific Culture (CSC), IAPT in 1989 sought the financial assistance from the Ministry of Human Resource Development (MHRD. A 3 year time-bound project with an annual allocation of Rs. 10.79, 34.75 and 21.58 lakhs for the first, second and third year was submitted to MHRD. Responding to the IAPT's proposal, MHRD agreed to support the establishment of 4 CSC's in the year 1992 and a budget of Rs. 10.4 lakhs was released for the purpose. Khandelwal, then secretary of IAPT was appointed director of the project (Khandelwal 1991, 160). Besides MHRD, financial help came from a few of Indian physicists working in USA. For instance, Ram D. Choudhari offered a donation of $400 for establishing the Rural CSC's in Janta College, in Etawah, Utter Predesh. Similarly Baljit S. Gambhir had extended an assistance of $ 400 for the cause (Khandelwal 1991, 297).

Following the release of funds from MHRD, members of the association from all over the country were mobilised to approach educational institutions in their local communities willing to collaborate with IAPT in housing and establishing the CSCs. The interested institutions, as per criteria laid down for CSC, needed to establish a workshop for the fabrication of laboratory instruments, two halls and a gallery with some extra open space within the premises. Teachers with innovative ideas to develop experiments for CSC were asked to send their write-ups along with detailed specifications, i. e. the parameters involved in and the concepts to be developed through experiments. Besides physics, the experimental items from the applied sciences and technology were to be included in the CSC's activities. The teachers constituting local teams (including those from a non-physics background) to establish CSCs were supposed to collectively discuss the possible CSC exhibits (Khandelwal 1991, 160).

12 institutions, namely American Friendship School and New Horizon School, from Bangalore; Saint Anthony's College from Shillong; B. J. B. College affiliated to Utkal University, Bhubaneswar; BSP School System, Bhilai; Marathwada University; S. G. S. College, Chandigarh; Gandhi Smarak Nidhi, Nagpur; G. N. F. L. School, Bharuch; Janta College, Bakewar; Janta Mahabidyalaya, Ajitmal and Kisan School, Bhulpur--responded to the association's invitation. Notwithstanding the keenness of the institutions identified for establishing possible CSCs, majority of them could not work in line with the laid down criteria and were dropped as the contenders for the CSC's. Three institutions, namely-–the New Horizons School, Bangalore, BSP School Complex, Bhilai and Gandhi Smarak Nidhi Building, Nagpur were found suitable for establishing the Centres for Scientific Culture (Khandelwal 1992, 77-78). M. G. Further changes were made to finalise the 4 places for the CSC at Narmadanagar, Bhilai, Nagpur and Midnapor. Madhuben Shah, Tarnekar and Vishesh Mohabey, D. A. Deshpande adn S. C. Samanta were the ones who took the initiative for establishing CSCs at these places, respectively (Khandelwal 1993, 283-284)

Of these institutions, only the Gandhi Smarak Nidhi, Nagpur, in the final analysis could satisfy the criteria laid down. Midnapore College did not figure in the fray but was later included in the CSC scheme and became the second CSC. Still hoping for more proposals, IAPT sought an extension for the project from MHRD up to December 1993. Eventually, IAPT had to return the remaining sum of money to MHRD. This signalled the formal closure of the selection of probable CSCs (Khandelwal 1993, 284).

4.2.3.2 The Inauguration of the Centre for Scientific Culture (CSC)

The initiative for establishing the centre for scientific culture at Midnapore came from S. C. Samanta and M. R. Ray--a physics teacher and the principal (being a physicist himself), respectively, at the Midnapore College. A few of the physics faculty at Indian Institute of Technology (IIT) Khargpur extended their support for the cause. Consequently, on February 4, 1993, D, P. Khandelwal (as the director of the CSC project), inaugurated the centre. Being a joint venture between IAPT and the college, it was called IAPT-Midnapore College CSC. The inauguration was attended by the Dean of Sciences, Vidyasagar University and C. L. Roy, Head of Physics Department, IIT Kharagpur (Samanta 1993).

To initiate the activities at CSC, IAPT provided a grant of Rs. 1 lakh to the college for the purchase of equipment such as Linear Air Tracks, Rigid Pendulums, Coupled and Maintained Oscillators etc. On the other hand, CSC was expected to improvise and devise a number of cost-effective experiments as per the scheme outlined. According to Samanta, in the course of time, CSC developed a number of experiments relevant for the teaching of physics at schools and colleges (Samanta 2002, 424).

Gandhi Smarak Nidhi Amarawati Ashram at Nagpur was the second CSC opened by IAPT. The inauguration of the CSC took place on 28th April 1993. D. A. Deshpande played an anchoring role. The centre purchased equipment and improvised experiments mostly suitable for a school physics laboratory. A theme-wise collection of 30 experiments from optics and electricity were set-up in this newly established CSC (Deshpande 1993, 216; Khandelwal 1993, 334). On August 22-23, 1993, the CSC organised a workshop for school physics teachers from adjoining areas (Deshpande 1993, 335). Interestingly there are no reports on the Nagpur CSC thereafter and Midnapore CSC is the only centre figuring in IAPT's programs. How did CSC-Midnapore evolve over the years? The observation and analysis of the experiments and demonstrations devised and collected by the CSC is taken up in the fifth chapter.

4.2.4 Teachers' Reorientation in Concept Centred Experiments and Demonstrations

Considerable work was done in conceptualising and developing experiments as a major way of learning physics during ULP and COSIP projects. Now reorienting introductory and undergraduate teachers in using experiments for concept formation was taken up as one of the major objective by the association (Khandelwal 1988, 9-11; Joshi 1998, 75).[64] Having oriented, teachers were also expected to improvise experiments themselves (Patki, Desai and Dharkar 1999, 149-158).

Moreover, orientation programmes to be conducted by IAPT were supposed to be free from the limitations of the ones in practice. While characterising orientation programmes traditionally conducted, Patki argued, "The distinction, between what the teachers know and what they are deficient in, was seldom very clear to even the resource persons" (Patki 1997, 303). This was supposed to be the major reason for the dwindling impact of the reorientation programmes (Patki, Desai and Dharkar 1999, 149-158). Khandelwal (1987) had already stressed, "Teachers had to be oriented in their thoughts and philosophy, as also in the competence to handle new experiments, and designing their own experiments" (109).

Work in this direction began in 1992 (Khandelwal 1992, 10-12; Murthy 1995, 25-30). Streamlining the relevant proposal for the orientation of the teachers was discussed at the National Convention at Nagpur in 1993. The experiments selected or designed for the purpose were related to real physical situations and pursued in an open-ended manner without any preoccupation with verifying laws or measuring some physical constants (Nene 1993). Eventually orientation programmes for both undergraduate and higher secondary teachers took shape by 1996. Since the support of UGC, State Governments, Universities and professional institutions was essential for the conduction of the programme, the programme took around four years (1996

[64] See the objectives (page no. 90 of the chapter)

to 1999) to materialise. An account of the orientation programs for undergraduate and school teachers is treated in the following pages.

4.2.4.1 Orientation Programme for Undergraduate Teachers

With the sanctioning of a grant by the Physics Panel of the University Grants Commission (UGC) in 1995, logistics for a massive orientation program in for undergraduate teachers in integrating experiments in their was evolved in 1996. A group of 30 teachers from various Universities were to meet for 4 weeks in June 1996 at the Physics Department, University of Rajasthan for the identification and critical examination of an assortment of experiments. Experiments from each of the domains of physics were to comprise the proposed set of 100 experiments (IAPT 1996). With this kit-bag of 100 experiments, a comprehensive orientation programme for undergraduate physics teachers was proposed by the association. The entire activity with all the details of cost, designs, suggestions for maintenance and repair, etc., during the programme was proposed to bring out in book form (Shah and Majumdar 1997). The kit consisting of 100 experiments so collected were to be circulated widely at various universities. Moreover, this was to pave the way for the formation of a nodal centre for the orientation programs in experimental activity. Similar centres at other places in the country were to be established and cooperation and competition among these centres was expected to create conducive environment for further work (IAPT 1996).

Eventually a four-week workshop was held at the Centre for Development of Physics Education (CDPE), University of Rajasthan, Jaipur, from 30 September-28 October 1996 (Joshi 1998, 73-78). After the passing away of D. P. Khandelwal (he was the coordinator of the programme) in February, 1996, A. W. Joshi was made the new coordinator of the programme by the Physics Panel of UGC (Joshi 1998, 75). Out of 300 teachers invited to the workshop, thirty five applied for the workshop and eventually 27 of them participated in the orientation programme (Joshi and Sharma 1997, 230-234).

Though the experiments were devised by a group of participant teachers (termed as resource persons) no claim to novelty was made. The idea could very well have been taken from some published article, existing experiments and prior reflections by them or elsewhere. However, they were not exact replicas of the ones already existing. Most of these experiments (about 60), were tried-out by the participants in the workshop. The participants and resource persons in this workshop were to present these experiments at other venues, covering the entire undergraduate curriculum (Joshi 1998, 75).[65]

The programme to upgrade the undergraduate physics laboratory in its new avatar was introduced again in 2009. The program was entitled, "A revitalisation of the Undergraduate Laboratory". The aim of the project according to Patki was to make domain-wise compilations of undergraduate physics experiments and its dissemination among physics teachers for subsequent adoption in their teaching. The use of computers for data acquisition, processing, analysis and graphical display was introduced in the orientation programme (Patki 2009, 3).[66]

4.2.4.2 Orientation Programme for Higher Secondary Teachers

A programme to orient higher secondary level physics teachers was the next to follow. MHRD was approached for funding the orientation programme. Programme was to be conducted in 30 locations across the country

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[65] Domain wise distribution of experiments was: 15 in Mechanics, 6 in Heat and Thermodynamics, 13 in Waves and Oscillations, 18 in Optics, 23 in Electricity and Magnetism, 14 in Electronics, 17 in Modern Physics; summing to 106 in total. Resource persons from IAPT were: T. R. Ananthkrishnan, Somnath Datta, Rajesh Karparde, A. S. Parasnis, B. L. Saraf, P. B. Vidyasagar. Recourse persons and participants from CDPE in the Department of Physics, University of Rajasthan were: A. K. Arora, K. B. Bhalla, Usha Chandra, Anjali Krishnamurthy, B. C. Majumdar (retired) and Ashok Nagavat, Sudhir Raniwala, S. R. Sharma (retired), Y. K. Sharma, B. K. Srivastava and Y. K. Vijay.
Refer to A. W. Joshi and B. K. Sharma, "I-Special Workshop on Experimental Physics at the Undergraduate Level (30 September-26 October, 96): Reports," *Bulletin of the IAPT* 14, no. 7(1997): 230-234.

[66] Again a list of around 50 experiments as just discussed was to be published as a booklet. The ideas that four model UG physics laboratories would train teachers in different parts of the country were floated again (see in Chandrika 2008, 55-56). Subsequently a national level workshop was held at the Centre for Development of Physics Education (CDPE), University of Rajasthan. The workshop was dedicated to B. L. Saraf after his passing away in 2009 (Chandrika 2009).

(Khandelwal 1996, 21-23). Besides a number of demonstrations, at least 50 experiments covering the entire spectrum of higher secondary physics were planned for the orientation programme. A booklet providing a brief description of each of these experiments and demonstrations were to be brought out for further dissemination among the trainee teachers (Joshi and Sharma 1997).

The funds were sanctioned by MHRD in March 1996 and work began in May 1996 (Patki 1997, 303-304). A 45 days orientation programme was scheduled to be held in Sept 1996. At first a prototype laboratory was set-up at Ruparel College, Mumbai and a brief write-up for each of the experiments was produced. Eventually, with a few alterations, the first phase of the programme was executed in 1997.[67] Those teachers experienced in designing experiments and demonstrations as well as possessed the critical 'know-how' to undertake these activities were made the resource persons for the programme. Local manufacturers were asked to test, rectify and reproduce 20 sets of experimental kits. Finally, a 6-days' reorientation for teachers was executed at each of the 20 institutions identified across the country.[68] According to B. A. Patki the director of the second phase of execution of the project from February 1998 to 1999, on an average 23 physics teachers attended a workshop (Patki 1998, 252). Overall in both the phases of the reorientation, 3000 trainees from all across the country are claimed to have undergone the 100 programs with a financial outlay of Rs. 30, 85000. Trainee teachers were provided kits to carry out this work at their respective institutions. A follow-up programme was planned to see how trainee teachers had assimilated and executed the skills and knowledge acquired in their respective institutions. However, follow-up as per schedule could not be

[67] Khandelwal--the convener of the program, while alive, had reportedly prepared the list of experiments, identified centres and a group of experts from a host of local colleges, universities and the HBCSE, Mumbai (Patki 1997).

[68] The orientation programmes were conducted at Banglore, Shmoga, Madurai, Chennai, Khochi (Kochi), Rajahmundari, Nagpur, Mumbai, Aurangabad, Latur, Bilaspur, Ajmer, Rajkot, Kanpur, Agra, Khurja, Cattuck, Midnapore, Yamunanagar (Panipat, Delhi, Gurgaun, Chandigarh) (Patki, Desai and Dharkar (1999).

pursued to completion (Patki, Desai, and Dharkar 1999, 149-158). Consequently, no feedback on the impact of the orientation programme was obtained.

Summary and Conclusion

The renewal of science education at different levels in India was suggested by the Kothari Commission in 1966. Guided by the recommendations of the Commission, the Srinagar deliberations in June 1970 charted out a concrete blue print for the renewal of tertiary physics education. Consequently, the University Grant Commission (UGC) formulated ULP and COSIP programmes to renew the entire spectrum of undergraduate science education. Probably, it was the first time that under these projects teachers at the tertiary stage were assigned the task of developing textual material and laboratory experiments. Having worked for around one decade (1970-80), ULP and COSIP programmes were concluded.

Physics teacher in India saw PSSC and Berkley Physics as model for emulation, both in terms of intent and the nature of curricular outcomes it produced. Babulal Saraf's remark in the preface of *Physics through Experiments-1*, 1979 is testimony of this fact. In fact the recommendations of the Srinagar deliberation to a large extent appear to be the modelled in the lines of the PSSC and Berkley Physics. This is also apparent from the fact that the problems facing Indian physics education were deliberated with physics educators from USA, UK and Canada. The objectives formulated and programmes pursued by IAPT so far too seem to be largely in continuation of this trend via the recommendations of Srinagar deliberation and outcomes of ULP and COSIP projects (Khandelwal 1986, 30, 302). There were further developments in science and physics education during the 1970 and 1980s. A number of physics teachers moved beyond the typical physicist's perspective on education. When IAPT was formed in 1984, a significant amount of empirical work was already conducted on student's pre-scientific conceptiona and ‘conceptual change’ model. IAPT appears to remain oblivious of this work.

As a matter of policy, the textbooks were to carry IAPT’s logo (IAPT 1984, 34). Writing the series of *Horizon of Physics* fell within physics teachers’ expertise. As researchers, they were used to writing such articles. Writing textbooks from a pedagogical perspective demands an appreciation of a students’ perspective and just being a practitioner does not guarantee having it adequately. Wide range of research on alternative conceptions substantiates this point. No further step in writing textbooks or *Horizon of Physics* kind of text has been taken since then. Raising the standard of physics examinations at +2 and undergraduate level was another major programme IAPT took up during 1987 and 1988, respectively. The examinations were to provide a benchmark for the teaching-learning process at these levels. In essence replacing the excess of facts with concepts and ‘problem solving’ ability was the objective behind theoretical part (Part A and B) of these examinations. Similarly, adding conceptual and procedural knowledge required familiarity with experimental activity. Cultivating these abilities was the objective behind conducting experimental part (Part-C) of these examinations during 1992 and 1993.

It is recalled that Srinagar Conference (1970) had already recommended a voluntary examination for the B.Sc. students. The examination was supposed to serve as an index of aptitude for the students aspiring to pursue research carreers in future (UGC and UNESCO 1970, 2). In organising NGPE, IAPT appeared to give it practical shape. A sound beginning was made by partnering between NSEP and NCERT in 1992 and 1993. No collaborative venture on Part-C examination was undertaken by IAPT since then. Furthermore the International Physics Olympiad (IPOpiad) had made a beginning way back 1967 (Gorzkoskie 2007). Yet India did not participate till 1998. Lack of infrastructure deterred IAPT from taking a step in this direction.

Linking NSEP to the preliminary phase of the Indian National Physics Olympiad (INPOpiad) was the best IAPT managed to do in this regard.

Pedagogically, NSEP and NGPE appear to be improved examinations departing from the conventional pattern. Though the challenge for students and teachers with the examination was supposed to trigger further work, in reality it did not move beyond discussion between teachers and students (IAPT 1986, 84-86). In this sense examinations were meant to be diagnostic tools. For instance a number of instructional modules developed by physics education researchers are based on the identification of pre-instructional conceptions. Students' difficulties with conceptual, problem solving and experimental knowledge and skills are diagnosed on this basis (Meltzer and Thornton 2012). Due to lack of further engagement in this regard, no such perspective was adopted or developed by IAPT. As a matter of fact these examinations served as a measure of achievement or aptitude tests.

As far as experimental activity is concerned, significant work had already been conducted during the ULP project. As an outgrowth of ULP and COSIP projects, IAPT was in a position to popularise it wide and across the country.

The idea of the CSC conforms to the 'Science Teaching Centre' proposed during the Srinagar Conference in 1970. 'Science Teaching Centres' were meant to institutionalise the developmental work on textbooks, teachers' guides, laboratory manuals and instructional methods in colleges and universities. Establishing a workshop for the fabrication and maintenance of equipment and providing students opportunities to acquire fabricational skills essential for worthwhile laboratory work was a special feature of the science centre. Accordingly, Universities were asked to take up orientation programs for teachers on a continuing bases followed by sustained follow-up activity (UGC and UNESCO 1970). The decision to open four Centre for Scientific Cultures (CSCs) in different parts of the country was an expression of this aspiration.

Contrary to expectations, the efforts invested in the CSC did not receieve the appropriate response from the institutions applied for the project and IAPT members. To initiate the project ample amount of funding was sanctioned by MHRD. The requisite amount of funding was promised for the successive phases of the project (Khandelwal 1991, 160). The early decline of the Nagpur CSC puts a question mark on the involvement from associated teachers and IAPT as a whole. The Midnapore-CSC remains alive even today because it is ensured at least the threshold of engagement required to sustain it. The nationwide orientation of undergraduate and secondary physics teachers was relatively easier to accomplish. As mentioned earlier, the requisite amount of conceptual and skill related work required the organization of programmes conducted during the ULP and COSIP projects and elsewhere (for instance HBCSE). Now the requirement was to pool together the expertise and funding needed to execute this activity. This time too MHRD sanctioned the required funds for the programme. Consequently, though extended over 4-5 years (1995 to 1999) the IAPT fraternity was able to plan and execute the programme. The inability to pursue follow-up activity should counts as the weakness of this programme.

Chapter 5

Centre for Scientific Culture, Anveshika and Related Sites of Experiments

Redefining the role of experiment has been central to IAPT's engagement with physics instruction. This is reflected amply in the deliberations and concrete initiatives undertaken by the association via experimental part of NSEP and NGPE, conceptualisation of CSC and conduction of teachers' orientation programmes. Though, other pedagogical concerns, for instance, historical reconstruction of physics concepts have been discussed, the bulk of the engagement of the association is confined in developing and popularising experiments for conceptual development.[69] In order to understand the nature and extent of this work, observation and interactions were conducted at various sites. Centre of Scientific Culture (CSC) at Midnapore and Anveshika (a physics laboratory at Kanpur) figure as the major initiative undertaken by the association in this direction.[70] To explore the nature and extent of this work, visits to the Centre for Scientific Culture (CSC) at Midnapore and Anveshika at Kanpur, were made. Extended interactions with Ved Ratna on "Optics Kit" developed by him and K. C. Thakur were conducted at his residence in Delhi (Saraswati Purum, Rohini). Orientation programmes for teachers were attended in Delhi, Ambala, Chandigarh, Meerut, Digha Science Centre (Midnapore) and C. K. Majumdar Workshop at SNBCBS (Kolkatta). In addition to this visits to 3-day Annual National Conventions of IAPT at Jaipur, Kolkata and Chandigarh, respectively, were made to interact with IAPT members.

5.1 Midnapore Centre of Scientific Culture (CSC*)*

Out of the two Centres for Scientific Culture (CSC) that came into existence in 1993, Midnapore is the one that could sustain its activities over the years (CSC-Nagpur being the other). CSC-Midnapore figures as an alternative

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[69] Will be evident in chapter 6
[70] http://iapt.org.in/

physics laboratory for school and college physics run by the IAPT. To collect empirical data on the activities of the centre, a visit to the centre was made between 14th and 21st December, 2011. As it happened, the visit to this site coincided with the National Accreditation Assessment Council's (NAAC) inspection of the college (from Dec 16 to 18th 2011). As running CSC is voluntary work pursued by the college, it does not come under the NAAC's scheme of appraisal. Nonetheless it was showcased by the college before the inspection team as it was expected to add value to the college's academic activities. The inspection team could not observe the activities at CSC due to lack of time as well as the priority accorded to the assessment of the mandatory activities. Against the backdrop of the special preparations made for the NAAC inspection, I could meet the concerned resource persons and see some experiments (both low-cost and sophisticated ones) showcased at the CSC. In addition, a presentation based on CSC's evolution was made by S. C. Samanta before fellow members at the Annual National Convention of IAPT at Kolkata held between 26 and 28th October, 2013. This serves as the major source of data on CSC's activities.[71] The following section provides a description of the observations made at CSC and a summary of the responses provided by the teachers, students and laboratory staff involved.

S. C. Samanta, a former physics faculty at the college is credited for being the key person in initiating and sustaining the activities at CSC. An extended informal interview with Samanta and a brief interview with two faculty members from the department of physics associated with CSC forms the basis of the subsequent section. These interviews were conducted in the course of an extended stay at the college.[72] Responses to a number of broader questions are summarised below.

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[71] S. C. Samanta, "IAPT-Midnapore College Centre for Scientific Culture (CSC): An Overview", 28th National Annual Convention of IAPT, October 26-28, 2013 at Sant Paul's Cathedral Mission College, Kolkata. Paper presentation by Samanta was made on 28th October, 2013.

[72] As stated by Samanta on 15th Dec 2011 at Digha Science Centre, he was in-charge of the initiatives undertaken by the college in establishing and sustaining CSC from the year it was established (1993) to 2008 when he retired from the college. Makhanlal Nanda

Figure 5.1 **A** *View of Midnapore College*

Figure 5.2 Front and Side Views of CSC-Midnapore

1. *What led to the formation of CSC?*

With to the initiation and subsequent evolution of CSC, Samanta stated that in 1989, Vidya Sager University (the University Midnapore College is affiliated to), made project work a compulsory part of its undergraduate physics curriculum and along with his colleagues, he was asked to initiate activities to enable this reform. He then approached physics faculty of IIT Khargpur to

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Goswami and Tanushri Pal Ghosh both as students as well as faculty had witnessed the evolution of CSC's activities from its formative years. The former was in-charge of CSC during my visit to CSC.

seek guidance for the execution of project work. In response, some of the physics faculty from IIT Kharagpur enthusiastically supported this effort and shared their expertise. Subsequently, for the next 3-4 years project work was consolidated as extended laboratory activity at Midnapore College. Having gained some preliminary experience, students developed a positive view of the efficacy of project work.

Samanta further stated that in 1993 IAPT invited proposals for establishing Centres for Scientific Culture (CSC) from educational institutions across the country. Midnapore College already had created an environment receptive to undertake this task. As a means to assemble and improvise experiments at the CSC, IAPT provided textual material in the form of a book *Physics through Experiments* with a collection of a large number of experiments on school and college physics. In addition, the centre was supplied a set of the experimental equipment like Linear Air Track, Digital Timers, Single and Coupled Pendulums, Barton's Pendulums etc., developed at the Centre for Development of Physics Education (CDPE), University of Rajasthan. This was part of the proposal to provide material and financial help to each of the upcoming CSCs during their formation.[73] On its part, CSC was expected to generate its own resources and devise a collection of demonstrations and experiments.[74]

2. *How did the work on experiments at CSC evolve?*

The task of guiding students through project work turned out to be an educative experience according to Samanta. In fact he considers the students as important contributors to the success of the effort. According to him it was all with the help of his students he could work to evolve CSC. Rather than

[73] The experimental apparatus were purchased for Rs. 1 lakh with financial assistance provided to CSC during 1993 (Samantha 2002, 424). The statement was reiterated by Samanta on 19th Dec, 2011.

[74] Response was given by S. C. Samanta on 15th December, 2011 at Digha Science Centre (West Bengal). I accompanied him to the workshop entitled "State Level Workshop in Chemistry: 16-18th December, 2011" at Digha Science Centre (West Bengal) organised by Science Centre Golkuachawk, Midnapore on the occasion of International Year of Chemistry.

acting as an authoritative figure as generally happens the case with most part of the teaching work, it was more a process of learning and sharing together from each other. It also provided opportunity to learn from his colleagues at Midnapore College and IIT Kharagpur. He added that as his interaction with students was informal and extended in time, pursuing experimental activities in open-ended manner became intimately engaging and enriching experience for all of them. While pursuing project work, very often, he and students had to pass through the moments of ambiguity and uncertainty and eventually resulted in understanding and acquisition of manual skills.

Having engaged with the formative and developmental activities of CSC, Samanta has developed the view that if pursued earnestly, project work may be the best way to go about open-ended experimental activity. Being a cooperative activity it is effective way to educate students in laboratory activities. He narrated a typical story of one of his students whose protracted engagement at CSC gave him a wholesome experience. The expertise his students earned at CSC, in part, helped him to qualify for scientists' position in national research institutions. However, rather than a norm, this was an exceptional case.[75]

Tanusri Pal Ghosh, now a faculty at the department of physics, while recalling her initial experiments at CSC as an undergraduate student in the early 1990s said:

> It was at CSC that first time in my life I could think that it is fine to commit mistakes while assembling and setting experimental activities. Atmosphere was made open and congenial for learning experimental activities. Slowly and gradually, I could feel the touch of the apparatus and shed of my fear of not being able to handle them well. Asking questions and finding answers with the teacher and fellow students, as a matter of fact, became an interesting engagement. The process in a way helped demystify the learning of physics and looked like a humanly activity which every students was naturally capable of. Even interesting was the realisation that teacher and students may work together as partners as there did not

[75] 15th December, 2011, Digha Sceince Centre, West Bengal.

remain a wide gap between the understanding and skills of teachers and students.[76]

The students present at CSC appeared to echo the views expressed by her and the experiences in project work as mentioned by Samanta.[77]

Figure 5.3 S. C. Samanta Working with the Students at CSC-Midnapore

3. *What is the assemblage of experiments and demonstrations that CSC has come up with?*

While making a presentation on CSC during the IAPT annual national convention at Kolkatta in 2013, Samanta pointed out that over the years CSC has been acting as a venue to carry out 'project work' (part of the curricular

[76] 19th December, 2011, Midnapore College, West Bengal

[77] Students appearing with S. C. Samanta in the figure, along with their co-participants in the "C. K. Majumdar Memmorial Summer Workshop in Physics organised by IAPT and S. N. Bose National Centre of Basic Sciences (SNBNCBS), 01-12 July, 2013" reiterated the view.

Having been initiated by the regional council (10) at Presidency College (Kolkata) during 1999, 10 days' workshop is organised annually during the month of June or July. Various colleges or institutions located in Kolkatta and adjoining areas act as the venue for the workshop. Satendera Nath Bose National Centre for Basic Sciences (SNBNCBS) has been the co-orgrniser of the workshop with IAPT (Regional Council 10A). Generally around 30 undergraduate students on an all India bases are selected for the workshop. Majority of them happen to come from adjoining areas and states. The experiments presented in the workshop, are devised (or improvised) by the institutions and individuals from around the country. For instance, segments of these experiments evolved at Midnapore College Centre for Scientific Culture (CSC), Homi Bhabha Centre for Science Education (HBCSE) and National Competition for Innovative Experiments in Physics (NCIEP) as well as teachers from various colleges across this region (Chakrabarti 2003, 2005). Experiments encompass both the school and undergraduate courses.

After the demise of C. K. Majumdar (an eminent sceintist) in 2002, as a mark of respect for his contribution in physics research and education, the workshop is named after him.

activity) undertaken by undergraduate physics students. The work of both students and technical staff, particularly K. K. Raul, to a large extent has resulted in the assemblage and improvisation of a number of experiments.[78] Some of the demonstrations and experiments (for example, Barton's Pendulum) shown in this table were showcased at CSC events.[79]

4. *What are the issues, other than pedagogical work, guiding the activities of the CSC?*

In addition to the academic work, sustaining CSC demanded the work on other fronts. For example, as mentioned by Samanta in a bid to have a separate space (rooms) for CSC in the initial years, the College was implicated in legal battle with for the ownership of the building CSC is housed in at present. It was only after winning the case in the court of law that CSC could have enough space of its own within the building in the neighbourhood of the college (now part of the premises of the College).

Funding has been another problem constraining CSC's progress and sustenance. Having received a preliminary grant of Rs. 1 lakh provided by IAPT in 1993, the centre has been suffering from a lack of funds to sustain and

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[78] Samanta, "IAPT-Midnapore College Centre for Scientific Culture (CSC): An Overview," (2013). Following is a sample of experiments (carried over the years as project) provided by S. C. Samanta the presentation of this paper:

1. Two wave interference on water surfaces.
2. Electromechanical arrangement for measuring frequency of an AC source.
3. Measurement of bond number in benzene and dipole moment of water molecules by optical means.
4. Use of diffraction technique to study depression of beams and thermal expansion of rods
5. Second order phase transition in ferrite rod
6. Verification of Clausius-Clapeyron equation using a pressure cooker
7. Verification of Malus' law and Brewster's law using Polaroids and LDR
8. Determination of Planck's constant using scooter bulb, prism and LDR
9. Boltzmann distribution; Band gap of silicon studying reverse bias characteristics of a rectifying diode
10. Measurement of magnet Magnetic moment of a coil carrying current
11. Variation of permeability of iron with magnetic field using magnetic levitation set etc.

Beside physics, CSC devised some chemistry experiments and intends to include experiments and models from Life-Science and Environmental sciences in the near future (Also reflected in the booklet on ASPIRE Training Programme-2007.

The list of the titles of demonstrations and experiments collected and improvised by CSC-Midnapore is provided in the appendix 4:"The manual for the physics laboratory kit developed by CSC-Midnapore,"

[79]Based on the observation during CSC, Midnapore

enlarge the canvas of its activities for long time. The monthly grant of Rs. 1000 was sanctioned by IAPT to CSC during its Annual National Convention in 1997. This to some extent helped CSC sustain its activities.

After having established rapport for around two decades, CSC is able to generate funds from the government and other agencies. Samanta stated: “Now days fund is not so much a problem. There are avenues to generate funds. For instance, ‘Surve Siksha Abhiyan’ (SSA) and ‘ASPIRE’ Programmes, of Government of India are channelized towards this end. And in fact, at present, CSC is involved in the assemblage and supply of experimental-kits to some schools for making physics teaching exciting.” With the aid coming from Government, the CSC extended its activities further to some of the Adhiwashi (Tribal) schools in the state.[80]

5. *What was the impact of CSC on the learning of physics through experiments and demonstration?*

In congruence with the objectives of CSC, there was provision for demonstrations and hands-on experiments for physics and chemistry courses at the secondary level. CSC on quite a regular basis has provided guidance and support to science students of Midnapore College in preparing their projects and models as curricular and co-curricular activities like participating science competitions etc. Moreover, with the introduction of laboratory activities and projects at the higher secondary level by the West Bengal government, the interaction between the science teachers’ from the nearby region and CSC has increased significantly.[81]

Furthermore the CSC at Midnapore has become the centre of a number of other academic and related activities. It has attracted the attention of the academic community from far and wide and thereby helped in the expansion

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[80] Samamta, at CSC, Midnapore College, 19th Dec, 2011
And Samanta, “IAPT-Midnapore College Centre for Scientific Culture (CSC): An Overview,” (2014).

[81] According to Samanta, in 2013, the college received the best award in a science project competition for students organized by the West Bengal Government.

of the membership and consolidation of activities of the IAPT in the state of West Bengal. The location of CSC within the premises of the Midnapore College helped the host institution to accrue benefits of launching new courses and facilities. For instance, according to Samanta, Vidyasagar University granted the College permission for launching a post graduate course, and in getting the status of potential for excellence from UGC—a requirement for autonomous colleges. From the year 2013, the Regional Council (RC-16) with the permission of the government, decided to organize regular academic programmes in three Government Schools, established exclusively for Aadiwasi students, in the Jangle-Mahal area of West Bengal. As CSC is located in the proximity of these schools it takes the major responsibility on behalf of the RC-16.[82] Following this, while appreciating the involvement of CSC, Manabik Sansthan--a Non-Government Organisation (NGO), has proposed to support CSC financially and promote its activities.[83]

6. *What is the perception of IAPT members about CSC?*

Though CSC was established in 1993, the larger IAPT fraternity was introduced to its work in 1997—the year the Annual National Convention of the association was organised at the Midnapore College. However they do not seem to be very much familiar with the work accomplished at CSC thereafter. For instance, R. N. Kapoor (the person behind the work at Anveshika, Kanpur) stated that as CSC did not present its work before the IAPT fraternity outside West Bengal. It does not know so much about the nature and extent of the work conducted there. Similar expression was given by T. R. Anantkrishnan (from Kerala). On the other hand, IAPT members from Kolkata, for instance Bhupati Chakarabarti, with closer and longer contact

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[82] Initiatives taken by Ranjan Roy and C. K. Majumdar, it is claimed, played anchoring role. Ever since the organization of Annual Convention of IAPT at Midnapore in 1997, CSC has been getting academic and financial assistance from the 16th Regional Council (comprising West Bengal, Andaman and Nicobar and Sikkim. See http://www.indapt.org/index.php/councils) of IAPT. In addition to this, CSC on a few occasions has played a role in organising the 'C. K. Majumdar Workshops in Physics'.

[83] Samanta, "IAPT-Midnapore College Centre for Scientific Culture (CSC): An Overview," (2013).

with CSC over the years, expressed his appreciation for the efforts that have gone into the work at CSC.[84]

5.2 Anveshika Kanpur

The creation of Anveshika at Kanpur, in the year 2001 rejuvenated the IAPT fraternity. R. N. Kapoor (a close associate of D. P. Khandelwal) and Saraswati Gyan Mandir School (SGMS) have jointly brought Anveshika into existence. Kapoor set example before IAPT fraternity by reconstructing demonstrations and experiments at Anveshika. Interestingly it was around the age of seventy that he started working at Anveshika. As a result, Anveshika, inspired by the idea of Centre of Scientific Culture (CSC), is being seen as a prototypical school physics laboratory.

Figure 5.4 SGM School Kanpur

Visit to Anveshika were made on two occasions, first between from 5^{th} to 8^{th} September, 2011 and then from November 30 to December 11, 2013. The following is a summary of the responses of R. N. Kapoor and interaction with H. C. Verma and other teachers and students part of Anveshika over the years. The responses are supplemented by the observations conducted and

[84] R. N. Kapoor expressed his view in 2012 during second visit to Anveshika Kanpur from 30 Nov-11^{th} December, 2011. T. R. Anantkrishnan made his remark during 29^{th} National Annual Convention of IAPT (October 10^{th}-12^{th}, 2014) at Sri Guru Gobind Singh College (SGGSC), Chandigarh. Bhupati Chakravarti expressed his view during the IAPT's 28^{th} National Annual Convention of IAPT (October 26-28, 2013) at St Paul's Cathedral Mission College, Kolkata.

the documents accessed. Publications in Bulletin of Physics of IAPT are also referred wherever deemed fit.

Figure 5.5: Anveshika New Building

1. *How did Anveshika happen to come about?*

As described by R. N. Kapoor: `In the late 1999, he was asked by Prof. Arvind Kumar from Homi Bhaba Centre for Science Education (HBCSE) to identify a school for holding Indian National Biology Olympiad in the city of Kanpur. Having this concern in mind he sought the participation of some of the schools in Kanpur and Saraswati Gyan Mandir Inter College situated at the outskirts of the city. Ram Narayan Agarwal, the owner of the school was receptive and happily offered his school as the centre for the examination. While having a talk with the owner he happened to mention the need to make physics teaching interesting by the way of employing demonstrations and experiments by the teachers. Kapoor expressed his views on the need to overhaul the physics laboratory. The idea appealed to the owner and asked Kapoor whether he would like to start this work in his own school. It was an encouraging gesture and at first, Kapoor felt like not believing it. However, sensing the seriousness of the owner, he happened to say yes. Soon they put together a concerted act towards this end. In the month of June 2000, Kapoor was offered the basement of the podium in the school grounds and he was asked to assemble and improvise experiments the way he liked. He was provided with some furniture and was given a free hand to buy raw material needed for the work. Consequently, Kapoor could devise a sizeable number of demonstrations and experiments at this place called 'workshop'.[85]

Gradually the workshop began to attract the attention of the teachers, students and school authorities and a great deal of appreciation was showered for the work done. Observing the workshop taking shape turned out to be moment of rejuvenation for the whole IAPT fraternity. On its part, the association extended its support to develop it further. While being acquainted with IAPT's concerns and efforts for physics education, Saraswati Gyan Mandir School (SGMS) found a prospective partner to collaborate with. As a matter of fact, both, the association and the SGM-School formally entered into a joint venture on the workshop. This marked the formal arrival of Anveshika on the horizon.[86]

The school authorities began to think about increasing the scope of the workshop. As a first step, a separate space to locate the workshop was identified. A plot of 100 square feet was bought to construct a separate building for housing the workshop. In the succeeding years, the school suggested IAPT to buy a plot adjoining the Anveshika and asked IAPT to make it an enterprise of its own. IAPT did not find itself in a position to generate the required funds to buy the plot and could not respond affirmatively. Anveshika continued to reside within the building provided by the school thereafter. Having offered Anveshika moral, residential and financial support, SGM School had also earned laurels from far and wide. Moreover, the next generation management of the school has continued to support it.[87]

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[85] R. N. Kapoor on 6th September, 2011 at Anveshika Kanpur
[86] Ibid.
[87] Kapoor on 7th September, 2011 at Anveshika Kanpur

The ‘workshop’ was named Anveshika during the formal inauguration on 14th March, 2001. It was termed as SGM-IAPT-Anveshika. Etymologically, a Hindi word it means a site for exploration and inquiry.[88] Two personnel, on consolidated salaries, were appointed to provide assistance to R. N. Kapoor, in maintaining and further developing cost-effective laboratory equipment as well as in organising orientation programmes. Kapoor was asked to act as the in-charge of Anveshika (Kapoor 2001, 367).[89]

2. How was the repertoire of experiments and demonstrations developed at Anveshika?

To begin with Kapoor took up whatever idea struck or appealed to him and gradually over the years this led to a sizable number of demonstrations and experiments in mechanics, optics, electromagnetic etc. Though most of the experiments were meant for students of senior secondary physics, some of them were relevant to elementary and undergraduate physics as well. He expressed special fascination about the optics experiments and thanked Ved Ratna for sharing an interest and ‘know how’ with him.[90]

***Figure 5.6* R. N. Kapoor setting the Optical apparatus**

[88] See sgminternational.edu.in

[89] Laboratory assistants as well provided a grant of Rs. 24000 on yearly bases for the activities of Anveshika. IAPT on its part provided a financial assistance of Rs. 10000 for the year 2000-2001 to begin with. With this grant the workshop could purchase further material to improvise more experiments.

[90] Kapoor on Dec 2, 2012 at Anveshika Kanpur
Ved Ratna along with his co-worker K. C. Thakur developed a comprehensive set of cost-effective optics experiments for schools and college physics curriculum. The work is discussed in the next section of the chapter.

The demonstration and experiments developed at Anveshika over the years are listed in the appendix 5.

3. *What is the role accorded to experiments and demonstrations and what are the outcomes?*

Anveshika lays emphasis on the acquisition of concepts through experiments. As claimed, experiments and demonstrations placed here are not meant for pursuing fixed objectives, processes and outcomes as is the case with conventional experiments in school and college physics laboratories; rather they are meant to encourage exploration, formation and consolidation of concepts. While agreeing with the dictum that 'seeing is to believe', Kapoor said teaching through demonstration and experiments results in a better understanding of concepts as well as reduces the time expended in teaching significantly. Thus teaching with demonstrations and experiments can help the teacher finish syllabi well before time and invest the left over time in other important activities.[91]

4. What are the activities conducted at Anveshika?

Over the years a number of teachers and students from various schools and colleges from within and outside Kanpur have been visiting Anveshika (Kumar 2007). According to H. C. Verma, Anveshika has an open-invitation to students and teachers from outside to visit and learn physics concepts by performing demonstrations and experiments. Indeed at the first sight Anveshika appears to have a refreshing feeling and gives an impression of breaking away from the conventional laboratory. It evokes a sense of awe among earnest of the students and teachers. Very often, interested visitors are facilitated to explore experiments and demonstrations placed there as well as encouraged to find plausible answers to their questions they pose.[92]

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[91] Ibid.

[92] Verma on Dec 6, 2012 at Anveshika Kanpur

 

Figure 5.7 Students getting a feel of the laboratory and R. N. Kapoor teaching at Anveshika

Anveshika seems to make them aware that demonstration and experiments can be an exciting a task and something is amiss at their schools.

Occasionally, the repertoire of experiments and demonstrations has been taken to the doorsteps of the students and teachers. For instance, exhibition camps were organised at Kanpur and Dehradun in 2009 (Kapoor 2009). Following this Anveshika, over the years, has earned a widespread recognition for the work being done by it. Occasionally, schools and institutions around Anveshika also happen to buy some equipments or apparatus dealing with specific experiments.[93]

Besides construction of experiments, Kapoor has devoted a part of his time for teaching school children on a regular basis. This enhanced the synergistic relationship between the school and Anveshika. He has been the lifeline of Anveshika throughout these years: from the foundation of Anveshika in 2001 to 2013—the year he retired around the age of 80+ years.[94]

5.2.1 Anveshika and Teachers' Orientation Programmes

In the light of the developments taking place at Anveshika, the idea of a Model Physics Laboratory or Centre for Scientific Culture (CSC) envisaged long back by the IAPT took new avatar. H. C. Verma, in close association with

[93] Reiterated by Kapoor on Dec 3, 2012 at Anveshika Kanpur

[94] Based on telephonic information from Anveshika in October 2013

R. N. Kapoor and other fellow members, took up the task of spreading this work in other parts of the country.[95] With Anveshika in the foreground, Verma set out to evolve a series of orientation programmes to help them integrate demonstration and experiments in their teaching. Since then different modules of orientation programmes such as a 'one-day, 'three-days', 'four-days' and 'six-days' workshops for the school and college teachers have been conducted.

'One-day workshop' termed as 'Utsahi Physics Teachers' is introductory in nature and aims to provide exposure to the participants. The workshop is conducted throughout the year across the country.[96] For instance, an orientation programme organized from 6-8th September, 2011 at Anveshika and IIT Kanpur began with the resource person providing a demonstration of what Verma termed as "eye catching and entertaining experience with the physical phenomenon being presented". The demonstration was supposed to illustrate the counter intuitive character of the phenomenon. This was followed by an interactive session between the audience and the resource persons involving questions and explanations of the underlying working principle, processes and materials and equipment. The thrust of the programme was to facilitate participants become independent resource persons themselves and propagate the teaching physics through demonstration and experiments. To help participants initiate the task, they were provided with an experimental 'kit' termed as 'Physics Show Bag'. The presentation to be made by using this bag was termed as *Physics Show*. The 'kit' contained improvised and low-cost demonstrations. A write-up on theoretical description as well as practical implementation of the sample

[95] Verma is (during 2011 or 2012) a faculty at Indian Institute of Technology (IIT), Kanpur, and is well known among the Indian physics teachers and students as the author of a book *The Concepts of Physics*.

[96] For example, Vigyan Prashar (A government Institution at Delhi) and Vidya Bawan (Publication house at Patna) have funded the orientation programmes at Meerut (mentioned above). More than 200 teachers from various schools from Delhi participated in the orientation programme at Bidla Vidha Niketan, School Pushp Vihar on two occasions (7th September and 24th November, 2012).

experiments was circulated among the participants. A compact disc (CD) with the label 'Innovative Physics Teaching' and description of these demonstration experiments was provided along with a kit containing experiments. In turn, participants in the long run were expected to assemble and improvise more experiments at their own.[97]

The workshop was initiated by H. C. Verma in the year 2002-03 and since then participant teachers themselves have developed expertise in conducting their own workshop for new trainees. For instance, Rakesh Awasti (from St. John Inter College, Agra), one of the trainees from this batch has been conducting orientation programmes in various parts of the country as well as outside the country (like Dubai).[98]

Despite relatively few teachers using demonstrations and experiments in their teaching, the numbers are still significant. Motivation and potential in the participants to carry forward this campaign is made the eligibility criteria for participation in the workshops. That is, teachers willing to participate in the orientation programme have to demonstrate their conviction that after receiving training they would take this work forward at their respective schools and colleges. They are then invited for next phases of the training via 3-days and 6-days module workshops jointly organised at Indian Institute of Technology (IIT) Kanpur and Anveshika at SGM School.[99]

Teachers attending the workshops are asked to share their work with the fellow participants. Occasionally around one-month workshops for those on

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[97] Verma during addressing the participants on 6th September, 2011 in orientation programme at Anveshika Kanpur. Also at the the BVN-IAPT Anveshika Orientation Programme for Physics Teachers, 7th September, 2012 at Bidla Vidha Niketan School, Pusp Vihar, New Delhi.

[98] Rakesh Awasti at the 1-day orientation programme conducted by him on 3rd February, 2013 at Dayawati Modi Academy School, Meerut

[99] Verma on 6th Sep, 2011 Anveshika Kanpur and at BVN-IAPT Anveshika Orientation Programme for Physics Teachers, 7th September, 2012 at Bidla Vidha Niketan School, Pusp Vihar, New Delhi

the verge of entering teaching profession (like fresh M.Sc. graduates), have also been conducted.

Figure 5.8 R. N. Kapoor and H. C. Verma holding discussion with trainee teachers at Anveshika Kanpur

The first of such workshops, under the title "Teacher-taught Interactive Workshop" was held in the summer of 2005. 30 students and 6 teachers (one each from the participating school) from 6 schools had attended the workshop. The participants were provided with a functional understanding of various experiments showcased at Anveshika (Kumar 2007, 201). The course was run for almost 30 days and comprised a 100 hour orientation. 9 participants reportedly attended the course in 2006 while the number increased to 12 in the year 2007. The difference among the two types of orientation programmes lies in the depth and comprehensiveness of the conceptual understanding provided to the trainee (Kumar 2007, 261).

Since the laboratory is well-equipped, the NSEP Part-C (experimental component) was also conducted at Anveshika in the year 2003.[100] External agencies such as Vigyan Prasar, Takshila Education Society or Bharti Bhawan (a Publication house) etc from time to time have collaborated with Anveshika in conducting workshops.**[101]** Occasionally, manufacturers of laboratory equipment also get involved in orientation programmes.[102]

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[100] Kapoor on 4th Dec 2012, Anveshika, Kanpur

[101] In 2005, Vigyan Prasar and Anveshika came together to organise a workshop for school physics. Anveshika and IIT Kanpur jointly were the venue for a workshop from 2nd to 6th

5.2.2 National Anveshika Network of India (NANI)

Notwithstanding the various constraints and impediments, some of the teachers oriented at Anveshika do feel the need to break away from the traditional method of teaching physics and happen to be motivated enough to collect and develop a repertoire of demonstrations and experiments to integrate in their teaching.[103] A number of them have evolved their own kit of experiments. Over the years they have evolved as an expert in conducting orientation programmes for other teachers at various places. For instance, A. D. Mahajan (from Latur), R. K. Awasthi (from Agra), R. K. Mitra (from Lacknow), Sanjeeve Kumar (from Bhagalpur), B. C. Rai (from Patna), Bregech Dixhit from Auriya and Rakesh Kumar Singh from Patna are said to have developed such expertise.[104]

Overwhelmed by the response received from the participants (teachers and students) and parent institutions over the years, IAPT in 2010, initiated the replication of the Anveshika programme at other places across the country. It

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June 2005. The collaboration extended to a series of workshops conducted at venues outside Kanpur like Trivandrum, Cochin, Chennai and Bhubaneswar (Verma, 2005). Similarly, a workshop entitled 'innovative physics teaching' funded by Takshila Education Society and Bharti Bhawan, was conducted at Delhi Public School, Patna in June 2006 (Verma 2006).

[102] For instance, a manufacturer belonging to Ambala Scientific Instrument Manufacturers Association (ASIMA) from Ambala supplied 6 sets of resonance tube apparatus and promised to supply other experiments on order before the commencement of a workshop in 2004 (Kumar 2004).

[103] During my visit to a one-day workshop in Delhi, Meerut and other places, teachers appear to feel the need for the integration of demonstration and experiments in their teaching. However, when it comes to push them in this direction, most of them did not seem to be motivated enough. In general they find the prevailing conditions at their schools not conducive enough to take up the work. While working under the heavy obligation of leading students to master concepts and problem solving as per the requirements of the board or school leaving examination, they seem busy in this pursuance as ever. On the other hand, a significant number of them assert that they need to give private tuitions or serve in the coaching centres to compensate for the supposedly financial deficit in their salaries. As many of them simply want to sell their teaching expertise for earning money, they do not enrol themselves for 3-days orientation programmes. Apparently, only a very few of the participant teachers really have the motivation to replicate and develop Anveshika work.

[104] The orientation programme: "Vigyan Prasar-Anveshika National Workshop on Innovative Physics Teaching (NWIPT-07) 8th to 13th June 2007-Report Department of Physics IIT Kanpur". See also iitk.ac.in/~hcverma/NWIPT-07.pdf. Most of the participant teachers mentioned in the paper also attended 3-days orientation programme from 6-8th Dec 2011at Anveshika Kanpur.

was at the IAPT's Annual National Convention at Rajkot in October 2010, a training programme, 'Anveshika Loving Teachers Orientation Programme' (ALTOP) was launched to expand the network of Anveshika type organisations in the country (Verma and Kapoor 2010). According to Verma and Kapoor (2010): "ALTOP is a workshop planned for the potential key persons who have the commitment for physics teaching and can play the pivotal role in starting and running such a centre at their own place." (313). Not only are the participants expected to replicate the work of Anveshika (at Kanpur) but also extend the repertoire of experiments further.[105] Following this, the first 4-day Anveshika Loving Teachers Orientation Programme (ALTOP) was organised from 30 th October to 2nd November in 2010. Since then this programme has become a regular feature of Anveshika's activities. Besides orienting participant teachers into the integration of demonstrations and experiments in their teaching, they are offered the technical 'know-how' to run similar workshops and open Anveshikas at their respective places. As mentioned earlier, to accomplish the task they are assisted to make a collection of physics demonstrations and experiments for the purpose of conducting a one and half hour 'Physics Show' before a gathering of students, teachers, or general public. On their part, they are expected to add more experiments to the kit-bag. Each of the newly emerging Anveshika centres are expected to run physics shows for a 100 hours' with demonstrations and experiments annually (Verma 2010, 34). The upcoming new Anveshikas are being networked together under a programme called 'National Anveshika Network of India (NANI).

While Anveshika Kanpur has a building of its own the new Anveshikas are housed in a room or in a corner of the laboratory of the institution (school or

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[105] For example, recently in 2012, Pragya Nomani, a postgraduate physics teacher at Bidla Vidha Niketan School, Pusp Vihar, New Delhi, has begun anchoring of the programme at her school. The work is supported by her colleagues and administration. Having evolved a repertoire of demonstrations and experiments, Anveshika is becoming a site for organising orientation programme for physics teachers from time to time. Two orientation programmes on 7th September and 24th November, 2012, respectively, were attended at this site.

college), as is the case with M. S. Marwaha from Shri Guru Govind Singh College (SGGSC), Chandigarh. Sometimes because of the lack of space or lack of adequate support from the parent institution, Anveshikas are housed at the residence of teachers, for instance, Anveshika founded by R. K. Mitra at Lucknow.[106] The table below gives the location and names of teachers anchoring the developmental work at these Anveshikas under National Anveshika Network of India (NANI). The information holds true till 3rd January, 2015.[107]

Table 5.1 Locations of the newly emerging Anveshikas

S. No	**Place**	**Name**	**Coordinator**
1	Kanpur, Utter Pradesh	SGM	Amit Kumar Bajpayi
2	Agra, Utter Pradesh	RAMAN	R. K. Awasthi
3	Siwan, Bihar	SIWAN	Rajeev Ranjan
4	Kolkata, West Bengal	TAXXILA	Amit Kumar Jana
5	Lucknow, Utter Pradesh	MITRA	R. K. Mitra
6	Patna, Bihar	PATNA	Amrendra Narayan
7	Oraiya, Utter Pradesh	GO & GO	Brajesh Dixit
8	Munger, Bihar	VSS	K. N. Rai
9	Kolhapur, Maharashtra	GCG	S. A. Masti
10	Bhilkwadi, Maharashtra	SSB	Gajanan Patil
11	Pilibhit, Utter Pradesh	SAMADHAN	Laxmikant Sharma
12	Pilani, Rajasthan	BPS	Manoranjan K Singh
13	Hissar, Haryana	OPJS	Lalit Mohan Singh
14	Delhi	BVN	Pragya Nopani
15	Udhampur, Jummu & Kashmir	HAPPY	Mineesh Gulati
16	Vizianagram, Andhra PRdesh	FOCUS	Chandrashekhar Joga
17	Chandigarh	SGGSC	M. S. Marwaha
18	Dhanbad, Jharkhand	VIDYA	Arvind Kumar Pathak
19	Hyderabad, Telengana	VIBHA	Jitender Singh

[106] Shared by the participants on 6th September 2011 in the orientation programme at Anveshika at Kanpur. M. S. Marwaha was visited 11th of Oct, 2014 during IAPTS Annual National Convention during 10th-12th, 2014, at Sri Guru Gobind Singh College, Sector-26, Chandigarh

[107] http://www.utsahiphysicsteachers.com/resourcematerial/experiments/NANI-Demo-Booklet-Ver-0.03-Jan-2015.pdf. Amit Kumar Bajpayi took over from R. N. Kapoor as the coordinator of SGM-Anveshika (Kanpur) in 2012.

5.3 Laser Based Optics Experimental-Kit

The production of a set of 'Laser based Optics Experiments' encompassing school and undergraduate physics, is another initiative undertaken by IAPT members, namely--Ved Ratna and K. C. Thakur.[108] Due to relatively easy access to Ved Ratna in Delhi, the following description is based on the interaction with him at ASIMA exhibition at Ambala during 24-26th November 2012. Description is supplemented by his writings.

According to Ved Ratna it was due to American physicists Herbert H. Gottlieb and Simon George (having Indian origin and migrated to USA) that he was introduced to low-cost laser experiments during an orientation programme in 22-23 September 1996. In the year 2003, the National Council for Science and Technology Commission (NCSTC), Department of Science and Technology, Government of India, provided him a grant to conclude his work. As a result a kit on low-cost laser experiments was brought out in the same year (also see Ratna 2006).[109] The latter phase of the work was funded by IAPT. Having designed large numbers of these experiments, he has been demonstrating them to the various students' and teachers' groups.

The origin of Ved Ratna's undertaking is interesting. When he retired from the department of science and mathematics, NCERT in 1992, he wanted to utilise his expertise in tutoring students. However, on the advice from his long time revered teacher, Professor A. R. Verma (former director of National Physical Laboratory) that he decided to continue to work for the cause of physics education. He chose to work on the application of laser technology to design cost-effective experiments in optics. Having found a co-worker in K. C.

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[108] Ved Ratna and K. C. Thakur are the retired faculty members from the Department of Science and Mathematics Education (DSME), NCERT, New Delhi and Department of Physics and Mukund Lal National College, Yamuna Nagar, Haryana, respectively.

[109] Ved Ratna and Newton Rastogi from Delhi Public School (DPS), Moradabad gave demonstrations of Optics experiments along with M. S. Marwaha at IAPT's stall in the ASIMA exhibition at Ambala during 24-26th November 2012. Beside optics experiments, number of other demonstrations from elementary physics was made by them.

Thakur, the duo took up the development of a set of optics experiments for school and undergraduate laboratory work in physics curriculum.
Beginning around the mid-1990s, the work took almost a decade or more to evolve and consolidate. Ved Ratna had earlier played a key role in preparing manuscripts of 2+ physics textbooks as a part of reconstruction of curricula by the NCERT (see: NCERT's 1989 physics textbook). On retiring and lack of infrastructural resources at his disposal, he could not lay his hands in designing experiments with technical sophistication and high costs. The 1990s witnessed the onset of the application of laser technology in devising cost-effective experiments in optics, and he thought it feasible to learn about the work already done in this area and develop a version of it suited to the Indian context.[110]

Unlike the experiments at CSC and Anveshika, the 'Optics Kit' produced by Ved Ratna and K. C. Thakur incorporate the documentation of both qualitative and quantitative features of the experiments. The detailed account of the procedure, measurements and the accuracy of the results of these experiments has enabled authors to circulate them widely among physics teachers at schools and colleges. The work reflects professionalism in the curricular field. Probably Ved Ratna's experience of a curricular worker at NCERT equipped him to produce such refined work.

Unlike other fellow IAPT members, Ved Ratna is critical of the avocation that low-cost experiments be used for illustrating concepts and principles qualitatively. Instead the major objective of these low-cost experiments in optics is to help teachers and students develop the ability to perform quantitatively rigorous experiments with precise results. Consequently, these experiments appear to be contenders for the validation and subsequent inclusion in the school and college curriculum. An exposure to the kit is intended to inspire students to take up experimental activity as project work

[110] The titles of the experiments are given in the 'Manual of Low-Cost Laser Experiments' developed by Ved Ratna and K. C. Thakur (2003). Refer to the appendix 6

(as provided in the syllabi) and conduct rigorous experiments (with precision of measurements) with the help of laser technology. Since experiments are less time consuming and handy, they also seem to be suited for demonstration of the concepts and principles of optics in the classroom setting.

After the publication of the first manual on the optics experiments kit in 2003, Ved Ratna demonstrated these experiments before a number of teachers and students' groups and helped them to pursue these experimental activities as project work (part of the curricular activity).[111] The list of the titles of these demonstrations and experiments is provided in the appendix 7. This activity led to further development of experiments from class VI to undergraduate curricula. Furthermore, the authors K. C. Thakur and Ved Ratna in 2006 came up with the 'optics kit' for class Xth.[112]

In fact, in the following years, the 'Kit' on optics experiments was deployed to train a number of teachers from Delhi, Haryana and Punjab. A limited set of kits were produced on demand from some of the schools on a no-profit bases. Eventually, in the year 2012, in order to propagate the use of the kit on a mass scale, the design was given to a commercial manufacturer.

5.4 Exhibition of Demonstrations and Experiments at various sites

Way back in 1994, it was a matter of chance that IAPT discovered A. H. Devadas—an exponent of demonstration experiments before a gathering of teachers and students at the 8th Annual National Convention of IAPT at Vijaywada (Khandelwal 1994, 28). D. P. Khandelwal floated the idea of institutionalising the work of Devadas (Ibid., 24). Though, the association did not undertake any formal activities in this direction, its repercussions were felt subsequently. According to Ved Ratna (2006), the encounter with Devadas

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[111] Ved Ratna, "Low cost Laser based demonstration Experiments in Optics," (yet Unpublished under the logo of Indian Association of Physics Teachers, 2006): 1-41

[112] Optics–Kit for class X is the title of second manual developed by Ved Ratna and K. C. Thakur that came up in the year 2006.

appeared to stimulate the imagination of the IAPT members for developing the skills for 'science shows'—the pedagogical component of the CSC.
Were these 'science shows' different from classroom demonstration experiments? Ved Ratna opined that 'Stage shows' based on the demonstration of real experiments, could generate interest through amusing exhibitions, tricks or magic shows. However, the scientific explanations offered for the seemingly inexplicable tricks helped make the transition from fun to the understanding of scientific ideas. He added 'science shows' cover the concepts relating to a topic or a whole chapter from the syllabus, a classroom demonstration generally picks up a specific principle from the lesson being delivered and occasionally offers an illustration through demonstration experiments (Ratna 2006, 283-289).

Devadas's inclusion in IAPT's activities inaugurated the era of exponents of demonstration experiments such as M. G. Tharnekar, V. D. Lalchandani and the likes.[113] A number of Anveshika workers and IAPT members at other venues are following the footsteps of these exponents.

The demonstration experiments part of the teachers' orientation programmes or 'science show' together with the optics-kit by Ved Ratna and K. C. Thakur, Anveshika and CSC can be divided in three categories. The first category comprises of the qualitative demonstration of physical phenomenon. Basically these are based on improvisations and are convenient for displaying the phenomenon in the classroom or laboratory. They happen to be highest in number and can encompass elementary to undergraduate courses. The second category of experiments displays the variation of physical quantities without rigorous measurements and analysis of errors. Generally the devices or apparatus of these experiments are also based on improvisation.[114] The

[113] Insight obtained through personal interviews with Ved Ratna (in his residence) and R. N. Kapoor (at Anveshika, Kanpur) during 2013 and 2012, respectively.

[114] Most of the demonstrations and experimental activities (ideas, equipment and apparatus) presented at these sites cannot be considered original. Rather most of them are improvisation of the experiments already devised somewhere else. For instance, according to Ved Ratna, a large number of the experiments appeared to be drawn from

third category is of quantitative experiments with a provision for the rigorous analysis of errors. Being bulky in nature, most of them are better suited for laboratory settings. Illustration or mention of a sample of each of these categories of demonstrations and experiments observed at various sites is given below.

Motion of the centre of gravity of an irregular object: Centre of gravity is the point on which whole mass of the object is centred and can be exhibited by balancing the object on in. The demonstration was made by taking objects like a pen or an irregular disc. After locating the centre of mass of these objects (by placing it on fulcrum) it was coloured by blue ink and then thrown on the large horizontal paper sheet. The observation clearly showed that the ink mark (centre of gravity) moved through a regular trajectory while other parts of the object followed an erratic path. The demonstration illustrated as to how centre of gravity can be visualised as the point on which whole of the mass of the object is concentrated. The demonstration was simple, handy and required no expenditure.[115]

Effect of Free Fall on Magnetic Force of Attraction: Two ring magnets having tied together by a thread are held apart at a distance. The distance between the rings is enough to outweigh magnetic force of attraction between them. As a result they do not get attached to each other. However, when released, they get attached to each other. This appears to be counter-intuitive, for the supposition is that like at the rest position, magnetic rings should also remain

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the experimental kit provided in *Physical Science Study Committee's (PSSC) Physics* (Ved Ratna, at ASIMA Exhibition site at Ambala, 2012). Most of the improvised demonstrations through 'Physics Kit' are purchased from commercial centers. A cursory look on the Internet sources may suggest that these items have already been renovated or improvised upon by various agencies and are widely circulated by science and physics education groups in different countries. Hyderabad is referred to be one such centre in India by B. N. Das (one of the exponents of demonstration experiments from West Bengal) in his presentation at C. K. Majumdar Memmorial Summer Workshop in Physics organised by IAPT and S. N. Bose National Centre of Basic Sciences (SNBNCBS) at the premise of the later, in Kolkata, during 01-12 July, 2013. Some of them were micro-versions (in size) of the experimental set-ups placed at Science Centres.

[115] Demonstration was provided by H. C. Verma at Vidla Vidha Niketan School, Pusp Vihar, New Delhi at BVN-IAPT Anveshika Orientation Programme for Physics Teachers, 24th November, 2012 at Bidla Vidha Niketan School, Pusp Vihar, New Delhi.

detached during free fall. The audience (students or teachers) is compelled to think afresh about the scientific explanation that during free fall the apparent force of gravity acting on the magnetic rings becomes zero while the magnetic force of attraction being intact pulls them towards each other.

The apparent loss of gravity or weightlessness was also demonstrated by slightly reorganising the magnetic rings. Now they were hung on the opposite sides of the top of a bucket. The body of the bucket acted as a rigid barrier between the rings and does not allow them to come close due to the attractive magnetic force operating between them. When the whole system of the bucket and the rings is allowed to fall freely, the magnets get attached to each other.[116]

Magnetic Levitation: This is an example of learning science with fun. When the secondary coil of an iron core transformer is replaced by a movable aluminium ring (not tied like the coil) and inserted through the core, the primary coil repels the ring. The phenomenon is called magnetic levitation. In this case the current passing through the primary coil and the ring are in opposite directions and therefore experience a force of repulsion.

Figure 5.9 Jumping Ring at Anveshika-Kanpur

[116] Ibid.

When the aluminium ring is released from above, the current becomes stronger and stronger, resulting in increased repulsion as it approaches near the first coil. Consequently, the movement of the ring slows while moving down. At a certain distance, the downward fall of the ring stops and the ring is thrown up. If repulsion is not strong enough to throw the ring out of the vertical iron core, it comes down again due to gravity and then jumps up again and the movement is repeated again and again. Hence the apparatus is called the 'Jumping Ring'.

As soon as the eddy currents start building up in the ring, it is heated up. The heating causes an increase in the resistance of the aluminium and consequently decrease of current through the ring takes place. Now due to a smaller current in the ring, it is weakly repelled. However, after some time when internal heat generation balances the heat loss due to Newton's cooling, the temperature of the ring and its motion becomes somewhat steady. If another ring is inserted it is attracted to the first ring (because currents in them are in the same direction) while both of them are repelled by the coil.[117]
<u>Principle of Gyroscope using a rotating cycle tire</u>: A thread is wound on the axle (a cylindrical rod emerging out through the centre of the tire). The tire is given a rotational push through axle and then left suspended with the thread held by hand. Amusingly, the plane of the tire starts rotating (horizontally). The interaction (vector product) between moment of force acting on the axle and the torque acting perpendicular to the plane of the rotating tire, keeps it rotating in the horizontal plane. The demonstration captivates the audience and helps resolve the difficulties that usually arise while conceptualising vector product.[118] According to Verma, "Pahle dekhao phir sikhao-Learning Physics with Fun" should be the motto of physics teachers. Fun, surprises and joy (particularly at the elementary stage) should be generated for learning physics. This is an instantiation of the principle.

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[117] The demonstration was given by R. N. Kapoor when he was visited Anveshika-Kanpur between 5-8th September, 2011 and again between 30 Nov-11th December, 2011

[118] M. S. Marwaha demonstrated this experiment at IAPT's stall in the ASIMA exhibition at Ambala during 24-26th November 2012.

Following observation offers another occasion to substantiate aforementioned diktum.[119] Miniature forms of the 'Anti-gravity Cone', for example, placed at the Digha Science Centre, West Bengal, can infuse fun in learning physics. When two conically shaped plastic 'keeps' are joined at their wider circular ends, it makes miniature version of 'Anti-gravity cone'. When it is released on a smooth upwardly inclined metallic rail (rather than being parallel, rail track opens up at other end), it appears to move upward and runs counter to common sense.

Where does the trick lie? While the object as a whole appears to move upward, the centre of gravity of the cone, in conformity with the law of gravity, actually moves downward. The structure of the cone is such that the extreme narrow side of the cone moves upward on the diverging rails and the central conical part sinks down through the open space in between them. As the bulk of the cone resides in the central conical area, plane or axis passing through centre of gravity moves downward.

At first sight, students and teachers (those who have not observed it before) were seen to focus on the upward movement of the 'cone'. They could not think readily about the point of location of centre of gravity and its downward movement.[120]

The conservation of momentum and kinetic energy can be demonstrated by a number of pendulums hanging either at a fixed distance or adjacent to each other. When, a bob at the extreme end is released from certain displacement it collides with the next pendulum at rest. The successive head-on elastic collisions across the adjacent pendulums results in the same displacement of the bob at the other end. When two bobs are displaced at one end following

[119] H. C. Verma at IIT-Kanpur on 8th November, 2011 at IIT-Kanpur and BVN-IAPT Anveshika Orientation Programme for Physics Teachers, on 7th September, 2012 at Bidla Vidha Niketan School, Pusp Vihar, New Delhi

[120] The demonstration was made by Amit Kumar Bajpayi at IIT-Kanpur during in a 3-days orientation programme (6-8th, November, 2011) for physics teachers jointly organized by IAPT and IIT-Kanpur. 'Gravity cone' is generally placed at science museum, for instance Digha Sceince Centre in West Bengal.

similar mechanisms, the bobs (two) at the other end also get displaced with same amount. Similarly, displacement of three bobs at one end results in the displacement of three bobs at the other end.

A qualitative correlation between the velocity and displacement of the bobs at the two ends is a demonstration of the conservation of momentum and kinetic energy. This phase of the demonstration is qualitative. However, it can also be used as a quantitative experiment. The processes of exact measurements of masses, velocities and displacements of the bobs carried would make it a complete experiment.[121] At the C. K. Majumdar Memorial Workshop at Kolkata the oscillations of a single bob were computer-interfaced and the arduous measurement procedure was made manageable.[122] Similarly computer-interfacing of the system of multiple pendulums can change it to quantitative experiment.

Optical Illusion: When an object, for example a pencil, is placed between two plane mirrors inclined at certain angle, a number of images are obtained depending on the angle between the mirrors. Mirrors are hinged together for varying the angle between them. The joint system of mirrors rests upon a protractor meant for taking exact reading of the angle. When the angle between mirrors is adjusted at 90, three (following the formula, number of images = 360/ϴ -1) images are expected. As angle between the mirrors is reduced, number of images goes up accordingly and approach theoretically infinite when mirrors are place parallel to each other. Evidently, the arrangement is a simple, cost effective and convenient to use.[123]

The experiments part of the optics-kit developed by Ved Ratna and K. C. Thakur are the example of this kind. A sizable number of the experiments

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[121] Demonstration was observed at CSC-Midnapore on 18th December, 2011

[122] Demonstrations of computer-interfacing was made by A. Rahman—recipient of APS-RK Scholarship, 2010 at C. K. Majumdar Memorial Summer Workshop in Physics organised by IAPT and S. N. Bose National Centre of Basic Sciences (SNBNCBS), Kolkata, 01-12 July, 2013

[123] Demonstration was made by Rakesh Awasthi at Dayawati Modi Academy, Meerut on 3rd February, 2013.

pursued at CSC-Midnapore and Anveshika-Kanpur are also of this nature. Moreover, a large fraction of the demonstrations (being qualitative in nature) can also be converted to measurement experiments.[124] The computer-interfaced experiments such as the "Study of Double Pendulum using a PC'', "Measurement of Speed of Fan by PC Interfacing" and "Interactive Software to Explore the Phase Space Diagram of Harmonic and Anharmonic Oscillators" presented at the venue of 26th National Annual Convention of IAPT, 10th-12th October, 2011, also belong to this category.[125]

Summary and Conclusion

CSC was envisaged as a sort of synthesis of a science museum and school-college laboratory. Unlike the school and college laboratory buying experiments from industry, it was supposed to improvise and design new experimental activities and then popularise their use for learning of concepts. CSC was also meant to inform the general public in how physics and science can be learned through these experiments and demonstration (Khandelwal 1988/1991/1992).

Evidently, CSC did not evolve the way it was envisaged. Appraising CSC's work over the years, Samanta, stated: "It is true that in the long 20 years of its survival, CSC has not been able to attract the ordinary people as expected by Prof. D. P. Khandelwal and its activities were limited to the students and teachers in institutional settings".[126] Its sphere of activities could not break out of the confinement of school-college laboratory settings. Samanta's efforts were more cooperative than individual for he worked with his students. However, due to the absence of the formal documentation of CSC's work in the past, a well-informed conclusion in this regard is unwarranted. As mentioned by Samanta, it was basically project work (the curricular

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[124] Refer to the appendix no. 5, 6, 7, 8, and 9.

[125] 26th National Annual Convention of IAPT, 10th-12th October, 2011, at Centre for Development of Physics Education (CDPE), University of Rajasthan, Jaipur. The authors of these papers were the first, second and third prize winners at the National Competition on Innovations with Computers in Physics (NCICP)-2011.

[126] Samanta, "IAPT-Midnapore College Centre for Scientific Culture (CSC): An Overview," (2013).

requirement of the undergraduate physics course) that was galvanised into the developmental activities of the CSC. The convergence of the objectives of CSC with curricular requirements helped create alternatively a better ambience there. The project work no longer remained limited to formal curricular concern, instead there naturally evolved a synergistic exchange between the students and teachers. The extended and frequent interaction among students and teachers might have encompassed a significant range of conceptual and procedural knowledge to accomplish curricular objectives. As a result, in the course of time students began to come up with their own ideas and extend work at CSC further. Samanta pointed out that: "CSC has done a remarkable job in offering the facilities of a public laboratory in the sense that rather than a site or workshop for the improvisation of a repertoire of experiments it was a site where students have been working on projects and experiments and place it at CSC. The collection of some of these experiments stored at the centre, are utilised in providing further experience to the teachers and students by organising workshops."[127]

Samanta retired in 2008. Rather than involving himself into the design and improvisation of experimental activities, in his very words, he prefers to organise workshops for motivating science teachers and students within and outside Midnapore.[128] On the other hand, the present faculty of the physics department of the college appears to have a limited engagement with the centre and focus more on their own teaching and research. One wonders whether CSC could further develop as a prototypical site for the construction and improvisation of experimental activities envisaged by IAPT. Apparently, in order to be a viable possibility, an intense engagement from some of the faculty (working or retired) seems to be imperative.

R. N. Kapoor began improvising experiment as a faculty in VSSD Kanpur and has played key roles in organising the Part-C examination (experimental

[127] Samanta, "IAPT-Midnapore College Centre for Scientific Culture (CSC): An Overview," (2013).

[128] Samanta at Digha Science Centre, 15th, Dec, 2011

segments) of both NSEP and NGPE. Like Babulal Saraf, D. P. Khandelwal or Ved Ratna, over the years his engagement at Anveshika was pathbreaking. The work at Anveshika was supplemented by material and infrastructural support from the founder of the SGM-school, Ram Narayan Aggrawal as well as his successor.

Having laid the foundation by Kapoor at Anveshika, H. C. Verma took the work further to evolve a series of orientation programme for teachers. Fellow IAPT members and interested agencies came forward to support the initiative. As a result of the orientation prgrammes for the teachers, a number of new Anveshikas have come up in different parts of the country and culminated in the National Anveshika Network of India (NANI). Upcoming Anveshika's are still in their infancy. In order to replicate or take forward the work of Anveshika Kanpur, they need to generate funds and space to carry out the work further.

Though not conducted within an institutional setting, the 'Optics Kit' developed by Ved Ratna and K. C. Thakur is an exemplar before IAPT fraternity. As a faculty at NCERT, Ved Ratna already has a long experience in curricular reconstruction. Laser technology has helped make the optics experiments are handy in comparison to other versions. Unlike Anveshika and CSC—Midnapore, each and every experiments pertaining to 'Optics-Kit' is rigorously documented. However, though, several teachers from Delhi, Haryana and Punjab have been using the kit in their respective (schools and colleges), no scientific study has been conducted to test the validity of the 'optics-kit'.

Physics teachers popularising experiments for concept formation at various sites have claimed higher learning outcomes? For instance Rakesh Awasthi involved in the reproduction and expansion of Anveshika work have reiterated R. N. Kapoor's claim that, in contrast to the commonly held belief, teaching through demonstration and experiments not only reduces the time of teaching considerably but also results in higher conceptual understanding in students.[129] H. C. Verma opined that even a 5 minute demonstration per period on consistent bases may enhance learning 10% and can bring about significant changes in the long run.[130] Though the claims made by the teachers stem from the empirical experiences, no scientific data is furnished by these teachers. The PER findings do not suggest straight forward higher learning outcomes however. Simply making demonstration of a concept through experiment before students or involving them in experimental activity does not guarantee conceptual gain in them. Hypothesis formation and its validation or refutation through demonstration or experimental activity is necessary for conceptual gain in students (Svedruzic 2008; Guemez, Fiolhais, and Fiolhais 2009).

Are IAPT members pressing for further renewal of teaching through experiments? According to Samanta, earlier experiments were meant to promote conceptual learning, now they will be integrated with 'problem solving'.[131] Making experimental side of the problem-solving explicit through concrete activity is anticipated to result in an increased learning among the students. For instance, problem-solving relating simple-pendulum is proposed to be tied with the corresponding experimental activity. Similarly, two pendulums of nearly (not exactly) equal lengths can be arranged side by side and the phenomenon of dissonance and consonance can be demonstrated experimentally and linked with its problem-solving counterparts.[132] The view was also echoed by H. C. Verma while giving a lecture on the development of

[129] Assertion was made by R. N. Kapoor on 7th Septermber, 2011, H. C. Verma on 8th, November, 2011 and Rakesh Awasti on 3rd February during my visit to the Anveshika Kanpur and Meerut, respectively.

[130] Argued by H. C. Verma while giving a presentation as a resource person at the BVN-IAPT Anveshika Orientation Programme for Physics Teachers, 7th September, 2012 at Bidla Vidha Niketan School, Pusp Vihar, New Delhi.

[131] Samanta, "IAPT-Midnapore College Centre for Scientific Culture (CSC): An Overview," (2013).

[132] In fact four such experiments were presented by the physics teachers from Midnapore at the 28th National Annual Convention of IAPT, October 26-28, 2013 at St Paul's Cathedral Mission College, Kolkata. See the related references under the titles—"Design and Solution of Numerical Problems in Physics through Experiments "followed by the names of the domain, for instance 'mechanics'.

Anveshika at the venue of 29th National Annual Convention of IAPT, October 10th-12th, 2014.[133] In the absence of scientific investigations on prolonged bases, the work of these physics teachers' remains far from being theorised. When extrapolated in research activity and theorised, the idea appears to approach closer to the one proposed and validated by a number of physics educators involved in developing concept inventories and the related instructional modules (Meltzer and Thornton 2012), in particular by Hestenes (1987, 1998, 2006), Halloun (2007) and Kurki-Suonio (2010) or in Indian context Khaparde and Pradhan (2009).

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[133] 29th National Annual Convention of IAPT, October 10th-12th, 2014, at Sri Guru Gobind Singh College, Chandigarh.

Chapter 6

Experimental Activity, Research and Pedagogy

Continuing with the major programmes and activities pursued by the IAPT, this chapter discusses the National Competition for Innovative Experiments in Physics (NCIEP), centre for physics education (CPE), physics education research (PER), pedagogy of physics. The chapter concludes the programmes and activities of the association as well as pedagogical stance taken by it.

6.1 National Competition for Innovative Experiments in Physics (NCIEP)

Rather than limiting the role of experiment to verification of theory or determination of physical constant, IAPT took stance to enlarge its scope to the development of concepts. The use of experiment for the development of concepts was termed as 'concept-centred experiment' (Khandelwal 1987, 109-113; Joshi 1999; Datta 2001; Joshi, Raybaghkar and Surve 2002, 2003). The 'concept-centred experiment' entails explication of the various facets of physical phenomenon to the fullest extent possible. The thrust to proliferate the idea of concept-centred experiment drove the formation of CSC, and Anveshika as well as conduction of teachers' orientation programmes. Besides these sites, a number of teachers have been engaging in the designing and improvising experiments at their individual levels. With a view to promote the interaction among them as well as reward their work, a competition termed as 'National Competition for Innovative Experiments in Physics (NCIEP)' has come into existence as one of the primary activities of the association.

The programme has its beginning in a seminar on "Innovative Experiments for Undergraduate Physics" held on March 22, 2003 at the physics department of Scottish Church College, Kolkata (Samanta 2003).[134] The objective of the

[134] As claimed, more than 80 teachers from various colleges in and around Kolkata presented experiments improvised or designed by them. Experiments drawn from different domains of physics, namely, thermal physics, electronics, optics, solar photovoltaic, and electricity were presented at the workshop.

competition was to provide a common platform to those teachers introducing a novel element in the experiments at the school and college levels. Since its inception, in 2003, the event has become one of the key activities conducted at the venue of the Annual National Convention of the association (Chakarabarti 2003; Ananthkrishnan 2004). As per rules, experiments have to be relevant for introductory (+2 level) physics. The ten best entries were called upon for demonstration at 18th Annual National Convention of IAPT held at Jalandhar from December 18 to 20, 2003 (IAPT 2003, 321). Generally, a group of teachers, acting as judges, hold discussions and reflect upon the problems confronted by the participants. Participants are motivated to further refine these experiments (Chakarabarti 2003; Ananthkrishnan 2004, 50-52). Prizes of Rs. 5000, 3000 and 2000, respectively are granted for the top three experiments to compensate for the expenses incurred (IAPT 2003, 321).

The competition was initially open to all the age groups. However, mostly senior members on account of their longer experience won the competition. In order to encourage young teachers, the participation of the senior members was restricted from the year 2005. Nonetheless, their expertise and suggestions form an integral part of the competition. The competition was also opened to the teachers outside the IAPT fraternity as well (Ananthkrishnan 2005). Over the years the participation in the competition did not increase as expected. In order to allow steady growth of the program senior members were allowed to participate from 2010. Entries were invited in two age categories, 'forty five and below' and above forty five. This was proposed to be merged in a single category in 2011. Also entries from undergraduate physics were made the part of the competition (IAPT 2010, 377-380). Some of the entries (for the years 2003, 2006 and 2007) in the competition are provided in the following table.[135]

[135] Refer to Anantkrishnan (2004, 402-405) and Anantkrishanan (2007, 2008).

Table 6.1 A sample of demonstrations and experiments from NCIEP

Title and description of experiment	Author and year of publication
A complete set of cost-effective and improvised apparatus for the demonstration of reflection, refraction, diffraction and polarisation.	Bhagwan D. Chakradeo, 2003
Improvisation of a cylinder-piston arrangement to study projectile motion.	Bhagwan D. Chakradeo, 2003
Resonance with utensil and principle of Jal-Tarang: The set-up consists of a simple pendulum suspended with its metallic bob extremely close to a metallic utensil resting on a glass plate. A loud speaker connected to an A. F. signal generator produces sound vibrations and are picked up by the utensil. At resonance, metal bob picks up the large amplitude vibrations of the utensil. The experiment is used to find the natural frequencies of vibrations for vessels of different size, shape, thickness, materials etc. Moreover, the variation of frequency is also studies when water is added to the utensil.	Bhagwan D. Chakradeo, 2003
Conventionally, study of standing waves with Melde's Apparatus is performed by setting a string fixed to a speaker oscillating in its natural frequencies. Generally, the speaker is driven by a sine wave obtained from a function generator. However, when the waveform driving the speaker is replaced with square or triangular wave forms, the string resonates with all the harmonics present in the waveform. Experiment serves as a demonstration of the Fourier Series.	Shastri, D. S. K. S., V. Deepak and S. Jha, 2006
Study of phase relationships and Lissajous figures by using old discarded computer monitors.	Sudha Girish Somani, 2006
A novel method of measuring the phase difference (by using microphone and CRO) in a liquid or gaseous medium.	Arun Parveen Chandra Patel, 2006
Measurement of refractive index using diffraction and polarisation effects: The light rays from a grating are allowed to pass through air or glass; diffracted rays are obtained on the screen. This is what is usually done in school laboratory. When the diffracted rays are also allowed to pass through plastic medium, the shift in the position of maxima takes place. The shift in the position of diffracted rays is used to measure the refractive index. On similar line refractive index of light can be determined by polarisation.	S. S. Tongonkar and V. R. Kadase , 2006
Computer-interfacing of Mass-Spring System	D. S. K. S. Shastri, 2006
When light is incident normally on the grating, the diffraction pattern is formed on the screen. The first order maxima are present on both sides of the central maximum. When one of the first order maxima is passed through medium 1 and other through medium 2, both the rays are diffracted and change in wavelength occurs accompanied by the change in the distance from central maximum changes. These changes are used to calculate relative refractive index.	Bhagwan D. Chakradeo, 2007

Continuation of the table

When two gratings are placed perpendicular to each other, two dimensional diffraction patterns are formed. Here there are four first orders of maxima. When these beams are passed through four different media, they too are refracted. Now, relative refractive index of any four liquids can be found simultaneously.	Arun Pravin Chandera Patel, 2007
The experiment studies the variation in time period of harmonic motion (of a physical pendulum) ranging from small oscillations to large angle oscillations by interfacing the experiment with computer.	M. R. Ganesh Kumar, 2007

Evidently, as shown in the table, most of the experiments have introduced some sort of extension, modification or improvisation. They offer alternative ways for measuring physical quantities (like refractive index); display a phenomenon (such as resolution of square waveform into its constituent harmonics, resonance frequency of materials having different sizes and shapes); and are cost-effective (handy and take minimum time for execution) in nature--for instance, demonstration of a large number of optical phenomenon. The introduction of computer inter-faced experiments make the measurement of physical quantities accurate and speedy as well as record readings for a large variation in physical quantity (for example, a shift from the linear to non-linear region, in case of the physical pendulum). As experiments and demonstrations are new addition (if not entirely novel), they may be valuable resources for exploration and consolidation of concepts. However as far as three years data suggest, the number of competitors has not risen significantly. Most of top rankers mentioned in the table above keep reappearing again.

Besides manual experiments, a computer application in physics experiments has also gained popularity among IAPT fraternity from 2000 onwards. A beginning was made at IAPT's annual convention at Chandigarh in the year 2001, where according to Samanta (2001), a large number of papers were presented on computer-interfaced experiments. The younger breed of IAPT members came out in favour of introducing simulations and computer-interfaced experiments. Though, the older generation still showed a preference for manual experiments, the stiff resistance posed by them to the introduction of computer application in physics experimental work in the past, was fading away.[136] To provide a common platform to these attempts, on the lines of NCIEP, a National Competition on innovation in Computer for Physics (NCICP) was initiated by the association from the year 2011 (Ananthakrishanan 2011, 185).[137] Mode of organising NCICP is on similar line to NCIEP.

6.2 Impending Centre for Physics Education

Till the mid-1990s, IAPT had already initiated its major programs. Concurrently the need was being felt to take steps towards the institutionalisation of the work. According to Khandelwal, having concluded ULP and COSIP programmes, UGC could initiate further work on physics education (akin to the text books and experiments developed in Berkeley Physics Courses). With this view in mind, he requested UGC to establish what could be termed as 'Centre for Physics Education' (CPE) or 'Science Service Center' (SSC). The centre was envisaged to provide the basic infrastructure such as a building, equipment and funds for developmental activities such as seminars and conferences, reorientation courses, and book writing etc. As a national centre, it should aspire to set up standards of the international level. As an association of physics teachers, IAPT was envisaged

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[136] Besides being handy and capable of quickly generating micro-data, computer-interfacing of experiments was seen to be cost-effective and therefore merited introduction in the physics education in India. In particular, Pratibha Jolly (one of the recipients of the APS-KR fellowship for the year 2004) was hailed by H. S. Virk, then president of the association, as the pioneer ushering in computer-interfaced experiments in physics education in India.
American Physical Society (APS)--K. Ramavatram Scholarship fund was established in 1983 with the donations from the family and friends of K. Ramavatram--an Indian origin professor of physics at Quebec, USA, at the time of his demise in 1977. The Scholarship supports Indian Physics Teachers in learning pedagogical methods for teaching undergraduate physics. The teacher getting the scholarship, after returning from USA, is expected to disseminate the knowledge and skills acquired there in the Indian colleges. Acknowledging the IAPT's credentials as teachers' association working for advancement of physics education in India, APR-KR committee, since 1984, had entrusted the task of selecting the fellow to IAPT, on yearly basis. Fellowship is exclusively a prerogative of APR-KR Committee and IAPT acts as a facilitating body.

[137] Anantkrishnan, T. R. *Bulletin of the IAPT* (2011): 185

to play a key role in developing and running the centre (Khandelwal 1985, 3-4). On another occasion, Khandelwal suggested that industries like Bhilai Steel Plant (hosting 21 secondary schools and a range of other schools) could be persuaded to establish a Centre for Science Education (CSE) on the lines of Homi Bhaba Centre for Science Education (HBCSE) at Bombay (Khandelwal 1988, 192).

Having this end in view, IAPT again looked up to UGC for support. However, the attempt to seek support from UGC and private institutions turned futile. Eventually, in 1995, IAPT contemplated on having its own academic complex under the rubric of Centre for Advancement of Physics Education (CAPE). Besides, institutionalisation of IAPT's programmes, the centre was proposed to undertake research activities in physics education. The academic complex was to have a campus with requisite structural components such as administrative office, laboratories, workshops, lecture halls, conference room, hostels etc. The executive council of IAPT, in September 1994, passed a proposal to generate funds for the aforesaid centre. The bulk of the funds required to build the centre were supposed to be generated from the personal contributions of its life members. In a bid towards this end a sum of Rs. 76, 771 is reported as a collection from the IAPT members (IAPT 1995, 284). This was targeted to be at least Rs. 5 lakh paving the way for the remaining fund collection from the donors from outside IAPT fraternity (Khandelwal 1995, 314). When established, the various national and international bodies were to be approached for the grant of recurring expenses. With representation from far and wide, CAPE was to be situated somewhere in the central region of the country (Khandelwal 1995, 314). On two separate occasions proposals for acquiring the land at Goa and Nagpur also came its way (IAPT 1998, 252).[138] However, the association had never

[138] Incidentally, an anonymous donor, as Khandelwal put it, offered IAPT a large hostel in a major town. A sum of at least Rs. 5 lakhs was required to be collected within 3 month for taking preliminary steps in this direction. Following this, the initiative for generating building fund was taken in January, 1995. Members were asked to contribute Rs. 300 per head for the purpose. Besides, personal contributions, Khandewal had earnestly urged his

been in a position to generate the required funds for the construction of a building. Nevertheless, proposals for such a centre kept popping up now and then. For instance, recently, citing the trend already set in the West, Kushwaha (2007) argued for a cell or unit for catering to developmental need of physics education.[139]

6.3 Physics Education Research (PER): An Uncharted Territory

It is well known that the large scale involvement of physicists during the 1950 and 60s produced quite an advanced curriculum (both at school and college levels). However, following the implementation and subsequent critique of the curricula during the 1970s, it was concluded that scientists or physicists perspective alone cannot deliver solutions to the problem of science and physics instruction (Cummings 2011). Thus the need to pursue a scientific approach in teaching and learning physics became evident (Hestenes 1979). Developments in science studies and cognitive psychology were drawn on to investigate the way students' actually learn science or physics. Science and physics education research (PER) as it is termed has complimented the curricular renewal since then (Duschl 2008). The American Association of Physics Teachers (AAPT) has been playing a pioneering role in establishing PER at the tertiary level. As a result, PER is seen as promising endeavour in

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fellow members to approach their affluent friends willing to donate Rs. 5000 for this purpose. Though Khandelwal appeared desperate to push the cause, the fellow members thought it was an impractical demand. Eventually the efforts in this direction came to a standstill and could not be sustained (Khandelwal 1995). In a similar vein, the attempts were made to raise Rs.10 lakhs to buy land at Nagpur (Murthy 1995, 25-30). Khandelwal called upon his fellow members to donate Rs. 500 individually (Khandelwal 1995, 314). He seemed to believe that if IAPT came up with a relevant piece of work in physics education, funds would come by readily (Khandelwal 1993, 4).

[139] Kushwaha (2007) stated, "There could be a Physics Education Cell (PEC) or a Physics Teacher Education Unit (PTEU) in the department of physics developing research based expertise for physics teaching. A close collaboration between physicists and physics educationalists, in this regard, is the need of the hour. Besides having a regular program for developing the teachers' understanding of physics as a discipline and its pedagogy, the PEC or PTEU would also look into the difficulties faced by physics educators which may be of variegated nature—presentation of an abstracted idea, showing a demonstration, using an educational tool etc and may chalk out its own research projects to arrive at a solution. In a span of time it is likely to evolve as the resource centre for physics teachers." (175).

the departments of physics in various universities the world over (Beichner 2009).

Where does the IAPT stand with respect to PER? Though still within the didactic fold, deliberation on PER appear to began way back in 1988. H. R. Anand (1988, 74), contended that teaching without research on the competing modes of teaching methods would be equivalent to be misinformed enthusiasm. But developments in this direction did not follow. IAPT's Annual National Convention held in 1999 provides a glimpse of the mind-set of the IAPT fraternity as regard to PER. Singh commented:

> At the recently concluded IAPT general Convention in Lucknow (Nov 1-3 1999) some of our colleagues from the Bengal Regional Council mooted the idea that the Bulletin should carry a regular feature entitled: "Misconceptions in Undergraduate Physics". A similar idea was also proposed by Dr. R. Popli of BIT, and Mishra (Bihar) who even provided an article on centripetal versus centrifugal forces for publication in the Bulletin. More to the point the keynote address at the convention was delivered by Dr. Arvind Kumar, Director, Homi Bhaba Centre of Science Education. He chose to speak on alternative frameworks in physics education.[140]

An affirmative response in relation to PER from IAPT fraternity was not sufficient. A similar proposal was also mooted by Joshi when he suggested that IAPT should set up a separate fund for Physics Education Research (PER). Again the proposal did not receive support from a majority of the IAPT members (IAPT 2001). On another occasion B. N. Meera emphasised the importance of undertaking research in physics education and its subsequent impact on learning, competency and lateral thinking among the learners at schools and colleges. She exhorted fellow members to take up physics education research in their colleges and universities (IAPT 2007, 13).

Arnold Arons (1998), one of the pioneers in the PER in USA opined that PER was initially either completely dismissed or viewed with great scepticism

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[140] Vijay A. Singh, "Editorial: Research in Physics Education," *Bulletin of the IAPT* (2000): 4.

(even with hostility) by almost all other physicists. Some physicists who fancied themselves as good teachers felt threatened. Others felt the work was simple and therefore not appropriate for physicists to pursue. Those who showed concern equated it to refining the delivery system--the exposition of text and lecture presentations to the point that they were so clear and so perfect that any passive student mind would assimilate them simply by having delivered it and that research might consist of finding out what students learning problem were (Arons in Cummings 2011, 7).[141] It appears that physics teachers in India, even after deciding to renew instruction for more than three decades have similar views about physics education research.

6.4 Pedagogy of Physics: Debates and discourses

Being counter-intuitive in nature, physics poses difficulties in conceptualisation (Wolpert 1992, 1-24). The difficulty is experienced in learning concepts, solving problems and in understanding the underlying meaning of mathematical equations and formalisms (Dikshit and Surve 1997, 251-253; Kushwaha 2000). Abstraction and mathematics in physics is beyond the reach of the average student (Virk 1989, 2000). However, command of mathematical understanding is considered inevitable for learning physics (Sood 1988, 238). It is not just the concepts but the inter-linkages among them which is essential, especially in regard to solving problems (Popli 2000, 202). In spite of being a typically interesting and exciting field of study, physics is perceived as a drab, dry and difficult subject by the students (Khuswaha 2000). Implicitly or explicitly, the entire endeavour of IAPT aims to reverse this trend. The section discusses the extent to which IAPT members have offered insights in resolving these problems of physics pedagogy.

6.4.1 Experimental Activity

Evidently, reconceptualisation of experimental activity has been a moot point in IAPT circles. In fact a major part of IAPT's endeavour comprises criticism

[141] Arons, Arnold. "Research in Physics Education: The Early Years." *Proceedings of 1998 Physics Education Research Conference*. http://physics.unl.edu/~rpeg/perc98/PERCpdfs.html

of the existing practices centred on experimental activity as well as expounding and popularising an alternative view on the subject. This is quite apparently reflected in the work on CSC, Anveshika, Teachers' Orientation Programmes as well as the 'National Competition for Innovative Experiments in Physics'. However, the alternative offered does not seem to be different or an advance over the one proposed during ULP and COSIP programmes or UNESCO Project on *World View of Physics*.[142] Instead popularisation of the pedagogical view already developed during these projects, appears to be the sole common denominator across all the activities IAPT have undertaken so far.

Here too D. P. Khandelwal led the campaign albeit the perspective was the one already proposed by him during ULP and COSIP programmes (refer to chapter 3). According to Khandelwal, instead of a straight forward verification of theory by measuring certain quantities, the role of experiments should be to help students learn the concepts of physics (Khandelwal 1987, 109-113). He termed this as 'concept-centred experiments'--as an alternative to the traditional verificatory or measurement experiment. Experiments designed to measure quantities such as gravity (g), Plank's constant (h), electric charge (e), or charge and mass of an electron ratio (e/m), according to Khandelwal, are optimised up to the skill of setting up experimental apparatus and equipment. For instance, in obtaining Newton's rings, focussing a microscope, making connections for an oscilloscope etc. Moreover, as parameters to be studied are pre-fixed for a given experiment, the procedure remains static year after year and does not evoke interest of students (Ibid., 110). Thus, it is urgent to re-define the role of experiments performed at the undergraduate laboratory (Ibid., 109).

Instead of providing a thorough articulation as to how experiment should become the central concern for physics pedagogy, Khandelawal, has relied on examples to substantiate his view. In a bid to explain what constitutes a

[142] See chapter 3.

'concept-centred experiment', he took up the example of the 'Two Slit Experiment' in the diffraction of light.[143] While performing the experiment of the Bi-prism fringes mentioned above, one just need not limit the student to 'determine' the wavelength of the light, as is conventionally done in the laboratory. Instead, one needs to examine whether the fringes are equidistant, see how the width of the fringes depends on the distance along the bench, or how it depends on the colour or wavelength of light and so on (Khandelwal 1994, 68). A number of other instances provided by him to illustrate his point are provided in the footnote below.[144] Concept-centred experiments deal with hitherto neglected areas of experimentation, for instance, capillary flow at large pressure differentials. As there is a change in the nature of the phenomenon, it is illogical to ignore this since no extra cost or effort is required and students can acquire an understanding of the nature of phenomenon in this region. This is case where experiment can precede theory (Khandelwal 1987, 112). Similarly, experiment on the physical pendulum

[143]By employing the relation $\lambda=b(2d)/D$; 'b' being the distance between two virtual sources, 'D' the distance between sources and screen, 'd' fringe width and 'λ' wavelength
[144] Following are the other instances where conventional experiment can be changed to a 'concept experiment', according to Khandelwal:

1. Obtaining 'localised interference fringes' with different pairs of slits as part of a single experiment. One learns how the shapes and sizes of the fringes depend on the surfaces chosen (Khandelwal 1987, 111).
2. Rather than limiting experiment to the physical pendulum in simple harmonic motion, the micro-details of harmonic oscillations, damping under various conditions, coupled oscillations, forced oscillations etc., should be the part of a single experiment (Ibid.).
3. Similarly conservation of momentum can be studied during all stages of an interaction or potential energy curves in various geometrical settings of magnets or oscillation in potential wells of a wide range of shapes, energy exchanges in elastic collisions. The experiment is termed as 'open-ended' as not only setting apparatus but also conducting observation, extracting, recording, analysing and interpreting the data are not pre-fixed (Ibid., 112).
4. A 'concept-centred experiment' has the scope for improvising, modifying or devising new experiments. For instance, experiment on 'Bending of a Beam' could be changed to 'Cantilever' experiment leaving a wide margin for the choice of loading and the position of measurement of depression. Here the bars of different materials and different cross sections can be used in the experiment. Rather than emphasing the calculations, the relationship among physical variables should be stressed (Ibid.).

(performed to determine-gravitational constant [g]), is limited to small measurements. Khandelwal further asserted, "Such verification type experiments are anti-science; they perpetuate a dogma in the students."(Ibid., 111). It can be studied for large oscillation i.e. in the non-linear region. He further contended, "Again, the widely used experiments 'such as the verification of Ohm's Law" is designed to prevent the child from going outside the range of linearity of V versus I. What an evil design really: Even the filament of a torch bulb would show fuller science; but we blind-fold the child from seeing that truth. How not to teach science must be examined closely."(Ibid.). Thus the validity of the laws can be appreciated when experiment extend the measurement beyond the region it holds true.

While reiterating his previous position (already elaborated in chapter 3), Khandelwal (1987) stressed that changing the format of conventional experiments from the narrow focus on pre-determined results to the study of the phenomenon would result in the concept-experiment. As may be inferred from the examples provided by him, the illustration of the physical phenomenon is minimal in the conventional experiment. To reveal concepts, the range and variation of physical phenomenon needs to be widened. The procedure for generation and analysis of the experimental data needs to be upgraded accordingly. Specifically, how the ideal curve defining the scientific law holds true for a specific range of data needs to be demonstrated. Experimental activity should generate data beyond this range to enable a broader understanding. Rather than streamlining the whole experiment to obtain a particular physical quantity, all possible relationships among physical quantities need to be discussed. How can this be realised? The variation in shapes and sizes of the constituent parts of experiment, introduction of new elements, connecting together two or more experiments etc. are suggested pathways. In addition to the teacher directed activity, performing experiments should allow students to ask questions, manipulate variables or even reconceive the experiment. Succinctly, the experiment should serve as a base for developing what is called physical intuition—the idea or concept emanating from the rich and meaningful experience with physical phenomenon (Koponen et al. 2003; Hestenes 2006, 24; Koponen 2007; Kurki-Suonio 2010).

Here too Joshi (1999), Datta (2001) and Mali (2001) were the other members using the term concept-centred experiment—basically a reiteration of Khandelwal's position.[145] Meaning thereby transformation of the routine experiment into the study of physical phenomenon requires a great deal of procedural knowledge--how to execute experiment productively for revealing the scientific phenomena. Apparently, they lay emphasis on the thorough explication of the physical meaning of the concepts, if not beyond.

6.4.2 Experiment and Mathematical Equations: Dichotomy or Integration

Mathematics is seen as the language for abstracting, defining, computing and connecting with physical reality—the major representational tool of physics. A large portion of a concept of physics is contained in mathematical equations and formalism (Gingras 2001). Traditionally, introductory and more so undergraduate physics is characterised by the deductive formulation of mathematical equations formalism as a pedagogic principle. While centering this experience with physical phenomenon are rendered sub-subservient to theory (Hestenes 1987).

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[145]Joshi contends that experiments performed in the undergraduate physics laboratory deal with the determination of physical constants, measurement of parameters or verification of some laws (for instance, determination of the wavelength of light, measurement of the refractive index, speed of sound or Young's modulus etc) (Joshi 1997, 187-189). Furthermore, Joshi (2008) states, "Unfortunately in our country; it has become a fashion to limit experiment in getting standard results, as given in books. Why to make fuss of accuracy and precision? As such these routine experiments do not offer a thrill or challenge to the students and help learn concepts and skills appropriately." (173). Like Khandelwal, Joshi asks, "We never answer the question like: how small should we keep the amplitude for reasonably good results? Should it be 5, 10, 20, 30 degrees? Or should it be 1 or even 0.5 degree for better results? Why not allow students to measure the time period versus amplitude right up to the maximum value i.e. 90 degree. Is it really difficult to get the time period for large amplitude? Can it be done with some advanced mathematical methods, which we teach any way at B.Sc and M.Sc levels, as an application of the method? What is the experimental criterion for simple harmonic oscillations?" (Joshi 2006, 119).

The compartmentalisation of the conceptual structure of physics into empirical and mathematical segments is seen as a major cause for students' difficulties in learning physics. The idea of unguided inductive-rediscovery of concepts or theory has already been discarded at the levels of elementary and introductory science (Hodson 1996; Kirschner, Sweller and Clark 2006). However, very often in a bid to reduce the excesses of deductive teaching, tendency to lay emphasis keeps arising from time to time at the elementary and introductory stages. As such it keeps intact what can be termed as empirico-theoretical divide of science or physics instruction (Koponen and Mantyla 2006; Koponen 2007).

Over several decades of engagement with PER, physics educators have offered a solution to the problem. The proposals of 'Model-based Instruction' (by Hestenes (1987, 1996, and 2006) and Halloun (2007) or 'Perceptual approach' in physics by Kurki-Suonio (2010) are exemplary. It was contended that unlike the high degree of autonomy developed by scientists as a result of years of training and experience, students needed to be guided in conceiving and devising experiments, extract data and translate these phenomenological experiences into concepts and mathematical equations. The empirico-theoretical dichotomy can be transformed into a fluid continuum between the empirical realm (represented by observation and experiments) and theory (contained in equations and formulae). Only after the acquisition of the optimum amount of phenomenological experience through successive grades in school or college can deductive illustration take precedence over building concepts from experimental activity.

What is the work done by IAPT members in this regard? Joshi and Tillu (1989) drew the attention of the Indian physics education fraternity at the lack of work in helping students understand logico-mathematical structure of physics and the conceptual structure underlying it. With a view to set an example, Joshi along with his fellow teachers from Pune University conducted a training program for B.Sc Physics students on this subject in the year 2008. The program claimed to explicate the relationship between hypothesis, postulates, models and approximations while relating physics and mathematics (Joshi 2008, 214-15; Joshi 2008, 240-245). Indeed the program was significant an attempt to diagnosis the difficulties students encounter in this regard, the treatment was based on lectures. Generating experimental data and translating it to mathematical modelling was not the subject dealt in the program.

Probably, Rakesh Popli happens to be among few of the second generation (after, Saraf, Khnadelwal or Joshi) of IAPT members offer an analysis of the problem on aforementioned lines. In a series of papers published between 1999 and 2002 he explains how both teachers and texts seem to fall short of addressing the problem.[146] For example, the gaps in students' understanding in relating kinematics-displacement, velocity, acceleration and average velocity, are brought about in his 2001 paper. According to him, difficulties arise because students are not generally shown how empirical data actually translates into relations among physical quantities or in mathematical equations. For instance, even how to generate the basic entities like rate of change of displacement or velocity on the basis of empirical data or what is meant by negative number in this context. According to him, merely following a 'formalistic approach' (mathematical formalism in physics) prevalent in practice, does not result in a firm and clear comprehension of concepts. For, instance, introducing students directly to the calculus and vector analysis can also impede the development of concepts of physics (Popali 2001, 202). Rather, the approach should be to provide students experiences of physical phenomenon through demonstration and experiments at the optimum level and then build up concepts and mathematical equations and the formalism up from there. He terms this the 'phenomenological

[146] For instance Rakesh Popli, "Physics Education in India: Some Unorthodox thoughts on Curricula," *Bulletin of the IAPT* 26, no. 9 (1999): 261-265.
Rakesh Popli, "Concepts and Misconcepts in Physics-I: Centripetal and Centrifugal Forces," *Bulletin of the IAPT* 27, no. 4(2000):106-109.
Refer to other papers by Popli

approach' and suggests that it be adopted at the introductory as well as college level (especially for the B.Sc. general students) (Popli 1999, 261).

Most of the IAPT members did not produce concrete work on the subject. Indeed lack of adequate explication of the physical content underlying mathematical equations has been a point of contention among IAPT member (Khandelwal 1994, 68; Ramani 2000, 58; Virk 2000, 233). They do not offer a well-articulated view in this regard and keep reinforcing the view limited to the physical interpretation of mathematical formalism (Kushwaha 2009, 183). Khandelwal (1995) preferred to lay emphasis on explication of the physical aspects, even if sometimes it meant excluding the mathematical formalism. This is apparent when he contends: "Fourier transform is of great interest; but whether its mathematical form is also, must need examination; the physical process behind it is more interesting. When the students go to M.Sc., they will learn the mathematical format" (100). On another occasion, by making reference of the relativistic mass i. e. $m = m_o\left(1-\frac{v^2}{c^2}\right)^{-1/2}$, he contends that mathematics provides a compact language for physics.[147] However, does the algebra contained in this formula explain physics sufficiently, he asks. Apparently, this is consistent with his idea of experimental activity (concrete and qualitative experiences) as the basis of conceptual learning rather than the mathematical abstraction (Khandewal 1994, 68). Khandelwal exhorted his fellow members that in "in our planning of physics education at all levels up to B.Sc. Let the emphasis shift from the rigorous mathematical formulas to simpler physical aspects of all laws and treatments" (Ibid.).

Desai seems to reinforce this view. While referring to the problem solving behaviour of physics students, he, argues that students very often resort to manipulation of formula and attribute it to the inadequate exposure given to students in experimental activity. Implying thereby that when students have

[147] Where 'm' is the mass of the object when in motion, m_o – mass of the object when at rest, v – the velocity of the object and c – is the velocity of light

had adequate learning in concrete experimental activity, the way for understanding and appreciating mathematical formalism opens up (Desai 2004, 305-306). Clearly, this stance presupposes a relationship between mathematical equations and the formalism and experimental activity. According to Ramani, the problem is not limited to the representation of the empirical data in mathematical form, but also bringing into light hitherto untouched or undiscovered parts of physical reality in experimental investigation (Ramani 2000, 59). Similarly other IAPT members express the need to relate experiments and mathematical equations but do not translate it in instructional approach.

6.4.3 Problem Solving in Physics

There is a general agreement among IAPT members that due to the poor uptake of physical concepts students do not acquire a confidence required for problem solving (Anand 1987, 314; Kushwaha 2000). It is amply clear that development of concepts through qualitative and quantitative enhancement of experimental activity has been the thrust of IAPT's work so far. Relating concepts to problem solving Anand (1995) asserts: "The ability to articulate concepts is largely ignored in such problems-dominated tests. In real life a prerequisite to problem solving is an ability to frame and phrase problems for which internalization of concepts and ability to articulate are the key requirements." (356). Should conceptual development and problem solving activity be related or acquisition of concepts via experimental activity or logical reconstruction separately is enough to move on to problem solving by students? IAPT does not offer a clear view in this regard. Its initiative was limited to the development of a repertoire of novel 'problem solving' items.

Holding a competition for devising (analysis being the integral part) novel problem solving items for introductory and undergraduate levels was adopted the way to move forward in this direction (IAPT 1986, 121). The best entries obtained were to be published in its *Bulletin of the IAPT* for the wider acknowledgment and inclusion in the repertoire of problem solving items so designed. However, when these were evaluated by the editorial board, it was found that very few good problems and solutions were provided. A few of the exemplar problems and their solutions, as well as articles on the techniques of problem-solving were published in the bulletin. Likewise, when the association invited entries for challenging problems, planned to be included in the IAPT examination (NSEP and NGEP), participation from the members, at least in the initial phase was lacking. Relatively few participants, for example, Anil Kumar, a physics teacher from Army Public School, Delhi being an exception, could earn the appreciation for making an exemplary contribution in the year 1987 (IAPT 1987, 24). Posing a challenging problem for readers and asking them to solve it was the another way to move ahead in this regard. Very often a separate section is devoted to this activity.

How does it contribute pedagogy? Certainly it is good for enriching readers' repertoire of problem solving. But when it comes to inculcate problem solving ability in students, it does not seem to be different from the method used in instructional practice.

6.4.4 Nature of Science and Physics

A meticulous and detailed portrayal of physics from historical and philosophical perspective is supposed to enhance the clarity of the ontological and epistemological underpinnings of the concepts. Traditionally, instruction does not emphasis on the explication of these facets of concepts. Instruction suffers from the lack of well researched and formulated content in this regard (Duit and Treagust 2003). Recognising the problem, IAPT members were called upon to develop a perspective on history and philosophy of physics. The members were urged to generate debates and produce useful material in this regard. As a response, a sizable amount of literature appeared in the *Bulletin of the IAPT*. It was agreed that an accurate and detailed description of the historical and philosophical development of scientific concepts enhance conceptual understanding (Khandelwal 1993, 164; Vishwamitter 1989, 2-3; Desai 2003, 39; Rajgopal 2003, 233; Joshi 2003, 368).

In order to illustrate the pedagogical significance of historical material, Khandelwal published an article illustrating how Newton's laws of gravitation can be situated in historical context vis-a vis the work of Tycho Brahe, Kepler and Galilio (Khandelwal 1984, 13; 1988, 127-128). For instance, he produced a refutation of the popular account that Galileo dropped two objects of unequal mass from the tower of Piecssa (Pisa) to account for their equal acceleration. He argued that proposition can be logically inferred and same could have been the case with actual discovery of the concept (Ibid., 13). Taking a critical stance on Indian education system, Desai, argues that the lack or absence of diversity of historical episodes limits the stimulation of the scientific imagination of students. Thus, besides applications of science in real life situations, the teaching of physics needs to be adequately infused with material on the historical evolution of scientific concepts. He stresses that references about the rivalry, successes, failures, vanity and other emotions of the scientists makes the teaching of physics human subject of study. With regard to the question "what form and extent of historical material is needed to be brought into the teaching of physics", Desai was of the view that though it may not be possible to give a detailed account of how science has historically evolved, however, a succinct presentation on the evolution of various concepts may suffice to enhance the understanding of the discipline (Desai 2003, 39). Similarly Joshi (2003) lamented:

> It is unfortunate that teachers do not pay enough attention to making physics appear as a plausible ensemble of hypothesis and theories to explain the observation of natural phenomenon. Every teacher tries to interpret physics and this leads to misconceptions. …this happens because teachers do not emphasise the role of axioms and hypothesis, laws of nature and the role of experiment. Teachers' present physics as a finished product, as a set of equation—something like this is the rule, this is the definition and this is the formula—without going into its development.[148]

[148] A. W. Joshi, "Misconcepts in Higher Secondary Physics," *Bulletin of the IAPT* 30, no. 8 (2003): 268-273.

Not many articles directed towards collecting and assimilating historical and philosophical material into the pedagogy of physics appeared. The initiative was restricted to the publication of a few exemplary articles on the issue. Instead of a rigorous analysis of the problem, in most of the cases, the articles raised concerns, lamentations or exhortation relating the need to work further in this direction. The publication of articles on history and philosophy of physics has decreased steadily over the recent years.

6.5 Conclusion of the Programmes and Activities of IAPT

Two distinctive phases, '1984 to 1996' and '1996 to 2013' appear to mark IAPT's engagement with physics education. In the first phase, IAPT aspired to carve out a space for the reconstruction of introductory and undergraduate physics education in India. The encounter with the existing social, economic and political milieu within which it had to operate, was a reality check for the association. Difference between what they aspired and the actual commitment they could show was apparent during this period. The second phase characterises the reorientation and limiting of its work within the boundaries dictated by the commitment of the members and the amount of support garnered from the government and private bodies. This section summarises the development and consolidation of the work of IAPT in pre-1996 (1984-1996) and post-1996 (1996 to 2013) phases.

6.5.1 IAPT's Programmes and Activities in Pre-1996 Period

Indian Association of Physics Teachers (IAPT) was founded with an aim to tap the potentialities of Indian physics teachers for the identification and resolution of the problems of Indian physics education, primarily at the undergraduate levels (IAPT 1984, 20). Though being foundational in nature, with the course of time, school physics became an integral part of its policies and programmes. Implicitly, the framework formulated by the Srinagar deliberation in 1970 for the development of physics education in India has served as the preamble for generating objectives and programs of the association. In the same breadth, the work of IAPT appears to be in continuation of ULP and COSHIP projects.[149] As an association of teachers relying exclusively on national agencies such as UGC or NCERT, the IAPT chose to chart out its own pathways for achieving its objectives. As discussed earlier, development of relevant textual material, creating benchmarks for examination in physics (NSEP and NGPE), preliminary activities towards the formation of 4CSCs and developing logistics for organising orientation programmes at secondary and undergraduate levels were the major programmes undertaken by the IAPT till 1996.

The programme for developing relevant textual material i. e. textbooks, monographs etc., did not evoke a favourable response from its members. The presumption that being the practitioners physics teachers in their individual capacities must have grappled with a range of problems relating to curricular content and method of physics, appear to drive the initiative in this direction. Now being a fraternity of physics teachers they stand at the vantage point. Apparently, task required rigorous debates and in-depth analysis of the kind of content and methods IAPT intended to develop. To begin with, two proposals to write books for +2 and undergraduate level came were placed before executive committee of the association (IAPT 1984, 85). The proposals were withdrawn within a year. As no proposal came forth individually or jointly thereafter, the programme of writing textual material was dropped altogether (IAPT 1984, 44).

Writing relevant textual material demands a fair degree of research on the subject. Articulation, explication and representation of tacit knowledge by the practitioners demand active and sustained engagement. This in turn demands the new ways of conceiving and investigating the subject matter (Schon 1995). The developments in the field of science and physics education over several decades substantiate this contention. To be able to produce alternative textual material, researchers incorporated the ideas from cognitive psychology and

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[149] Refer to the recommendations of Srinagar deliberation (chapter 3) and the objectives of IAPT chapter 4), respectively.

philosophy of science to interrogate the existing practice. With the course of time there arose a community of scholars on the subject where research outcomes were discoursed and peer reviewed.[150] Nothing of this sort appears to happen significantly within IAPT circle. Moreover, lack of funds could have proved it a difficult proposition to carry out the research needed to write the books.

In the absence of work on text book writing rhetorical arguments often mark debates and discourses IAPT circles. Rao contended, "Indian physics books borrow from standard sources and happen to be over-stuffed" (1988, 123). On the contrary physics textbook should be neither a mathematical textbook dealing with only inter-relationships or symbols nor a biological science text primarily descriptive in nature. A relevant physics textbook should be a judicious weaving of the generation of data from experimental process leading to concept development through abstraction and mathematical rigor. Beside this it should clarify the philosophical and historical perspectives on the subject matter. Therefore UGC should commission writing of the textbooks following these criteria with appropriate compensation and recognition to authors (Ibid.). Is it that textbook in India suffer from what Desai (2003, 237) terms as intellectual inertia--the practice of reproducing the ideas of others without understanding them. Kushwaha (2003, 255) appears to sum up the story by stating that the textbook writing in India hardly has any philosophy behind it.

As it happened, long term engagement from a few of its members did reach close to the production of useful textual material. Having worked for around a decade, Ved Ratna and K. C. Thakur have three manuscripts on the optics experiments that can be brought out in book form.[151] Similarly a manuscript was prepared by Rakesh Popli with some concluding work remaining. After

[150] Refer to see the PER products including books David E. Meltzer and Ronald K. Thornton, "Resource Letter ALIP–1: Active-Learning Instruction in Physics," *American Journal of Physics* 80, no. 6 (2012): 478-496.

[151] Refer to Ved Ratna (2003), Ved Ratna and Thakur (2003) and (2006).

his sudden expiry, the work could not be pursued further and has been brought out as a book.[152] Furthermore, the work already done at Anveshika-Kanpur or CSC-Midnapore could have been brought out in book form.[153]

The publication of the series of *Horizon of Physics* took of late but finally did succeed.[154] Since teachers and advanced students were the intended readers, it does not demand adoption or creation of novel pedagogical perspective. What it required was to break down of the content as dictated by the pedagogy already in practice. A cursory look at the content of first two volumes suggests that the bulk of this literature was an addition on the content in the textbooks, journals and other mediums. There were relatively a very few topics having novel perspective, for instance, "philosophy of science" by Joshi and Khandelwal (1995).[155] Third volume of *Horizon of Physics* was exclusively a compilation of research reviews suited for the postgraduate and M.Phil courses. The joint work during the production of the series of *Horizon of Physics* developed a sense of collegiality among the members and probably helped IAPT fraternity to evolve further as a cohesive unit. It is recalled that the objective of producing textual material, monographs etc was framed as one of the major objective by the association. Failure of writing textbooks and not extending the *Horizon of Physics* further put a stop on the further work in this direction.

The aim behind launching NSEP and NGPE in 1986 and 1987 was to set a benchmark for the school and college physics examinations in India.[156] Large scale participation in the programme not only brought IAPT members together as a cohesive group but also introduced it to the width and breadth

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[152] Book written by Rakesh Popli is entitled *Physics Textbook for Class XI* (IAPT, "Obituary, Dr. R. K. Popli," *Bulletin IAPT*, Nov (2007): 344).

[153] The work CSC-Midnapore and Anveshika has already been dealt in the 5th chapter. Refer to the appendices 4 and 5

[154] Refer to series of *Horizon of Physics* by Joshi and Hans (1989), Nath and Joshi (1996) and Gupta (2002)

[155] A. W. Joshi and D. P Khandewal, Understanding Physics from Philosophical Point of View," in *Horizon of Physics-1* ed. A. W. Joshi (New Delhi Wiley Eastern Limited, 1996)

[156] Refer to the objectives and activites laid down by the association (provided in chapter 4).

of the country. When the desired response in writing books did not come by, involvement in these examinations gave IAPT fraternity the needed thrust to move ahead. Even today, organization of NSEP and NGPE across the country continues to be the main activity pursued by the association.

Close collaboration with NCERT in 1992 and 1993 for conducting the experimental part of the NSEP examination was the highpoint of IAPT's collaboration with national bodies involved in curriculum revision. For a short period of time though, it raised hopes among IAPT members for opening up a debate on and reconstruction of the school physics experimental work in the country. In fact the construction of experimental activities to subject students to test their knowledge and skills was achieved in these two years and was expected to be standardised further (IAPT 1993, 175-179). However, NCERT's opting out of the joint venture in 1994 brought much of the generated enthusiasm to a standstill.

Probably as envisaged by IAPT, the analysis of the difficulties in conceptual and problem solving questions encountered by students could have opened the way for further discourse and research on NSEP and NGPE. Evidently, this did not happen (IAPT 1987, 194). A noteworthy outcome of NSEP and NGPE was that an appreciable amount of revenue, out weighing all the other grants from different sources, was generated by the fees charged from the examinees. The fee of Rs. 5 (NSEP) and Rs.10 (NGPE) per candidate charged in 1987 and 1988, respectively. It was raised to Rs. 50 and 75, respectively in the year 2010. Indeed the fee was nominal. Given the large numbers of students enrolling for the examination coupled with the voluntary service provided by the huge army of physics teachers, the revenue generated by the association was significantly high.[157] Though the donations and grants from individual sources as well as several national bodies was significant; the sum generated from the examinations contributed in a major way (for instance,

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[157] IAPT, "Minutes of the Executive Council Meeting of IAPT," *Bulletin of the IAPT* May (1988).
IAPT, "NGPE 23rd 2011, "*Bulletin of the IAPT* (2010): 287.

50.00% and 80.17% for the year 1988 and 2008, respectively) to carry out other activities of the association.[158] The funds generated from the examinations not only played a decisive role in providing financial independence to the association but also ensured its very survival and progress. Besides the financial aspect, the organization of the examinations helps the association in adding more and more members from remote regions of the country. Beginning was made with 1100 members in March, 1984 (IAPT 1984, 6-7). Now the network of teachers, researchers, administrators and students over the years has gone beyond 6000 in 2017.[159]

Initiating activities for the establishment of 4CSCs in India was the next program undertaken by IAPT in the first half of 1990s. CSC was conceptualized as a site to construct and store a rich array of experiments and demonstrations meant to provide experiences with scientific phenomenon not only for school and undergraduate physics but also exposing lay public (Khandelwal 1991, 130-138). The presumption that there are physics teachers, who not only have ideas to construct relevant demonstrations and experiments but also can give them concrete shape when requisite amount of financial and infrastructural support is provided to them, was central to work on CSC (see objectives of the association). In fact financial support of Rs. Rs. 10.79 lakhs was released by MHRD as first installment for the formation of 4 CSCs in different parts of the country (Khandelwal 1991, 160). 12 institutions selected as probable CSC, were supposed to provide infrastructural facilities. The formation and sustenance of CSC required tremendous amount of self-motivation and voluntary work on the part of the physics teachers leading the initiative. They not only required to display ingenuity in collecting, improvising and designing the varieties of experimental activities but also needed to invest in requisite amount of social skills to succeed in the

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[158] IAPT, "Account for the period January, 1988 to November 20," *Bulletin of the IAPT* (1988)
IAPT, "Income and Expenditure Account for the Year ended 31 March 2008," *Bulletin of IAPT* (2010).
[159] Refer to http://www.iapt.org.in/ to see the present membership of IAPT.

endeavor (Khandelwal 1992, 77-78). The response that came from the host institutions and physics teachers taking lead in setting CSC fell way behind the expectation. Only two institutions (at Nagpur and Midnapore) could fulfill the criteria laid down for the formation of CSC. CSC at Nagpur dwindled few years after being founded. Now CSC-Midnapore sustains as the only CSC. This reveals a lot about the nature and amount of voluntary commitment and application on the part of IAPT fraternity right at the onset of the programme but also the institutions enrolling for the probable CSCs.

6.5.2. IAPT in Transitional Phase

Till the year 1994-95, most of the programmes of the IAPT had been conceived and to significant extent executed. Now there arose the need to reappraise the nature and relevance of its work. By this time it also became evident that IAPT has not moved beyond the pedagogic perspective already conceptualised during ULP and COSIP projects. Babulal Saraf and D. P. Khandelwal were the central actors in the development of this pedagogic perspective. Most of the programmes were meant to collect, improvise or design experiments for enhancing conceptual understanding. Despite important developments the IAPT fraternity did not seem to review, adopt, critique or push their boundaries to produce alternative perspective on concept formation, problem solving or mathematical modelling of physics.

Challenges on other fronts were awaiting the association. Having been assured the relevance and timely completion of the establishment of 4 CSCs and orientation programmes for secondary and undergraduate teachers by IAPT, funding agencies came forward to support these programmes. However, IAPT was in need of more funds to carry out its programmes at a larger scale. Khandewal expressed his disappointment with the government in underestimating the potential of IAPT to renew physics education in the country.[160] Around 1993-1995, IAPT speculated the need to construct an

[160] Khandelwal's wrote a letter to then Prime Minister of India for not accepting IAPT's plea for the grant of funds worth Rs. one crore for expanding the work on centres of

academic complex to institutionalize its work on a sustainable bases. The task required substantial amount of funds. Collections from its members and seeking donations from affluent people eager to promote the cause of physics education were proposed the way out to generate funds (Khandelwal 1995, 314, 324). H. S. Hans--the second president of the association (for the period 1987-1988), wondered whether this order of funding could be collected through donations. Instead he suggested that the association forge ties with institutions willing to provide the association space on a temporary, semi-permanent or-permanent basis (Hans 1995, 171-172).[161] Eventually IAPT was left with no choice but to settle with opening two new offices at the Physics Department of Punjab University and Indian Institutes of Education at Pune during 1988 and 2001, respectively. First office was already operating from Kanpur since 1984 (IAPT 1988, 170-173; IAPT 2001, 127).

It can be recalled that IAPT, in the beginning was mandated to take up the problems of undergraduate physics. Being foundational in nature, subsequently, introductory physics was included in its scheme of things. Furthermore suggestion was made to extend its mandate to postgraduate teaching and research. H. S. Hans (1988, 1995) supported those members favouring extension of IAPT's activity to the post-graduate and research levels. As the Indian Physics Association (IPA) was already working at these levels, Khandelwal (1994, 24) countered the move to restrict IAPT's involvement to undergraduate and introductory stages.

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scientific culture (CSC). It was clearly an expression of desperation and unhappiness with the government's stance. See D. P. Khandelwal, "Open Letter to P. M. (Shri P.V. NaravimhaRao): IAPT wants only Rs. One Crore," *Bulletin of the IAPT* (1995): 324.

[161] Since its inception in 1984, IAPT has been functioning from its central office (at a private residence, first at D. P. Khandelwal's and then at R. N. Kapoor's residence) at Kanpur. Also it was granted a room by the department of physics, Punjab University of Chandigarh in 1988 (IAPT 1988, 170-173**)**. In the year 2001 when the journal of Physics Education was adopted by the association, IAPT hired a couple of rooms at the Indian Institute of Education-Pune for carrying out the publication of the journal. In fact this became the third regional office of the association.

A perceivable lack of involvement in the work of the association from a large majority of its members also turned to be a matter of concern in this period. Questioning the prevalent state of affairs Khandelwal (1995) lamented: "IAPT was established as a platform for those who were prepared to do something at their own without waiting in the wings. It started on sound ground, and went a long way in doing many things which do not need a recount. But, of late, we are finding that a similar trend is developing within the IAPT also" (292). He had to exhort his fellow members to adopt or rather invent some ingenuous approach to towards the achievement of the objective IAPT has set for itself.

Having been there as an association of physics teachers for more than a decade, IAPT has undertaken a number of programmes for the renewal of physics education in India. It not only seems to have realised the mitigating or facilitating role played by the social, economic and political factors on their work but also the nature and extent of individual and joint engagement by fellow members. Following section throws light on the next course of action pursed by the association.

6.5.3 IAPT's Programmes and Activities in Post-1996 Period (1996-2013)

The demise of D. P. Khandelwal, in 1996, appears to have an adverse impact on IAPT fraternity. Be it the formation of the association, proposing the idea of the CSC, debates and discourses on pedagogy etc., Khandelwal played a leading role. B. L. Saraf was the first president of the association and after Khandelwal's death the onus of steering the association fell upon him again. Due to his immense interest and exemplary work, he was considered the best person on whom fellow members could repose their faith and come together as a cohesive unit again.

Teachers' orientation was the first programme executed in the second phase of IAPT. IAPT members from various parts of the country put their efforts together to execute the projects of reorienting school and undergraduate physics teachers. Though planning of both of these projects started before

1995, their execution was extended till 1999. This set the trend for the similar orientation programmes conducted for teachers at regional and national levels subsequently (Joshi 1998, 73-78; Patki, Desai, and Dharkar 1999).[162] The programmes as per schedule did not gather evidence on to what extent teachers trained could employ experiments in their teaching and whether the results matched the objective or diverged from it.

Engagement with the preliminary phase of Indian National Physics Olympiad was the next programme pursued by IAPT in post 1996. NSEP and NGPE were not supposed to be limited to construction and addition of conceptual and problem-solving questions. Implicitly though, they were envisaged to be progressively revised. Idea to extend NSEP to India's participation in the International Physics Olympiad in 1995 was one of such a move (Srinivasan 1995; Prakash and Ratna 1995). Be it lack of infrastructural facilities, death of Khandelwal or general decline in the motivation level of the members, IAPT could not take initiative in this regard. Unlike IAPT, HBCSE having established itself as the premier centre for science education received the support of various national agencies to stake claims for organising preparatory programme for India's participation in the International Physics Olympiad in 1999. Ample funding from government ensured the financial success of the programme (Kumar 1999). IAPT entered into a collaborative act in the preliminary phase of this programme with HBCSE. IAPT's experience and expertise in organizing the NSEP across the corners of India, was used for the pre-selection of meritorious students not only for the Indian National Physics Olympiad (INPOpiad) but also its counterparts in chemistry and biology (Dharkar 1998). Playing a subsidiary role though, it was a moment of delight for the members of IAPT (Chattopadhyaya 1997).

Unlike NSEP and NGPE, INPOpiad is not limited to the organisation of the examination. Rather it is followed by a training programme focused on sorting out the difficulties faced by the participant students. Consequently,

[162] Refer to Regional Councils of IAPT in the footnote no. 24 and page no. 117, chapter 4..

while reconstructing the theoretical and experimental part of the INPOpiad by HBCSE, pedagogical engagement has become an integral part of this examination. It could be surmised that had IAPT put its act together the NSEP and NGEP could have resulted in the needed pedagogical engagement that HBCSE has undertaken since 1998 (Chakrabarti 2015).

There was a break in holding of experimental parts of the NSEP and NGEP examinations from 1996 to 2001. Even when the examination was revamped in 2001 the members did not feel inspired to improvise upon the examination. What was the other reason for the declining interest of IAPT members in conducting and developing the experimental part of NSEP further? Have they invested efforts to take up the work further? R. N. Kapoor contended that the organisation of the laboratory training for the trainees of International Physics Olympiad by HBCSE, in part, also made IAPT members complicit in conducting experimental part (Part-C) of NSEP.[163] No further reappraisal was conducted to fix or to reframe the nature of problem by the association. This appears to reveal the limits of their involvement in the reconstruction of physics pedagogy in India. The examination continues to be held on more or less on regular bases though without any pedagogical breakthrough.

Reconstructing a large array of demonstration and quantitative experiments and popularising their use in concept development was the objective with which CSC was developed (Saraf 1991). In this sense CSC envisaged to be a model physics laboratory for school and undergraduate physics and was inevitably a long term project. Though large number of institutions showed readiness to house and provide support to the CSC, eventually the lack of engagement from them failed the imitative. IAPT fell short of the set target of opening 4 CSCs in India. Midnapore was the one that could sustain as the CSC. CSC-Midnapore was set up with the idea of reviving school and college physics laboratory work more than two decades ago. From S. C. Samanta's perspective sustained efforts have been invested in developing the centre for

[163] R. N. Kapoor, 3rd December, 2012 at Anveshika-Kanpur (30 Nov-11 December, 2012).

several years now (Samanta 2013, presentation at Kolkatta). The curricular activity in 'project work' undertaken by the undergraduate students was extended into cooperative endeavour between Samanta and his students and some of his colleagues at CSC (Samanta 2011, interview at Midnapore). As a result, centre figures as a key site for reconstruction and proliferation of experimental activity.

IAPT's annual convention at Chandigarh in 2001, according to Samanta (2001), marked a water-shed in revival of IAPT after Khandelwal's death. The large scale gathering of members in the 'Annual National Convention' was the testimony of this fact. Y. R. Waghmare--then president of IAPT, played a role in reviving the association during his tenure from 1999-2001.[164] The greatest moment of joy in the Chandigarh Convention was when B. L. Saraf, remarked –"I did not commit any wrong in requesting Y. R. Waghmare to take over the IAPT leadership" and in reply Waghmare responded, "I would not disappoint you Sir". Apparently, as Samanta (2001), appears to suggest, with this the second generation leadership of IAPT emerged.

The establishment of Anveshika as a school physics laboratory at SGM School Kanpur turned to be a landmark event in the associations' attempts to base physics pedagogy on demonstrations and experiments. Exclusive and intensive engagement of physics teachers in the reconstruction of experiments and demonstrations is rare event, and more so after retiring from academic work for a long time. R. N. Kapoor's work was reminiscent of the work produced by B. L. Saraf's group at Rajasthan University, notwithstanding the differences in contexts. Like its predecessors, SGM School offered to play anchoring role in housing the reconstruction of demonstration and experiments. In fact it went ahead in providing financial aid for the work. However initiative taken by of R. N. Kapoor to improvise and design demonstrations and experiments was at the heart of the success of the

[164] According to Samanta, Y. R. Waghmare got credit for raising IAPT's stock of funds during his tenure. The presence of Prof. Yashpal—a celebrated physicist and educationist as the chief guest at the convention added prestige to the gathering.

Anveshika. Having hit at the root of the problem, Anveshika could inspire such work at other places like NCIEP and a number of locally organised workshops on physics experiments across the country under IAPT's banner were encouraged by Anveshika and its networking activities. At present, Anveshika is being sustained by SGM School and IAPT, especially by its members from Kanpur. The momentum for the popularisation of the role of experiments in concept formation is building up across the schools and colleges of the country. Improvisation and designing of experiments began to be pursued by other teachers at their individual level. NCIEP offered a forum for these efforts. 2001 Annual National Convention of IAPT was a watershed movement in the introduction of computer-interfaced experiments within IAPT circles (Samanta 2001). NCICP was a late entry into IAPT's programmes during 2011. However, introduction of computer-interfaced experiments in IAPT circles has already been made in the Annual National Convention of the association in 2001.

As substantial part of the work of CSC and Anveshika has not been documented, it renders formal evaluation and duplication difficult. On the other hand, the work done by Ved Ratna and his colleague K. C. Thakur's work turned out to be well documented and therefore making it amenable for being worthy for curricular adaptation. While large segment of the demonstrations and experiments at CSC and Anveshika are qualitative in nature, kit of optics experiments developed by Ved Ratna and K. C. Thakur is well recorded and quantitatively calibrated.

6.6 Pedagogical Stance of IAPT: Conclusion

It is intriguing that B. L. Saraf, pioneering the work of reconstruction of experiments during ULP does not appear to express his view actively in the debates and discourse within IAPT. On the other hand, D. P. Khandelwal translated his views into activities and programmes undertaken by IAPT. The role of experiment reconceptualised by him during the ULP programmes has since been reconfigured. Traditionally physics teaching was dominated the introduction of concepts through the derivation of mathematical equations and formulas and providing physical interpretations by performing verificatory experiments designed to obtain the final value of a physical quantity. Khandelwal wished to enhance the scope of experiment in exhibiting a range of physical dimensions, relationships and meanings underlying theoretical concepts. The idea was to develop in students what is very often called 'physical intuition'—rich and refined experiences of physical phenomenon serving as a raw material for developing perceptual ability. The perceptual experience of this vein when translated into symbolic form (language, graphs, diagrams and mathematical symbol, equations, and formalism etc) transforms it into conceptual understanding (Koponen et al. 2003). The revised experiment was called the 'concept experiment'. As symbolic version side of concepts has already predominance in traditional physics instruction, Khandelwal appears to lay emphasis on qualitative or perceptual experiences serving the base for the former.

The idea of concept-experiment was endorsed by fellow members, for instance, Joshi (1999), Datta (2001) and Joshi, Raybaghkar and Surve (2002, 2003). Implicitly or explicitly, programmes such as NSEP Part-C, NGEP Part-C, CSC, Anveshika and orientation programmes for secondary and undergraduate teachers were to translate the idea of concept-experiment into practice. Aim was to produce a large number of experiments in variety and quantity as possible and employ them for conceptual development in students.

Ghassib appears to through light on the subject. According to him, at the introductory and undergraduate levels of physics instruction a large number of concepts and derivations of equations come from classical physics where process of physical meaning making precedes mathematical expression. There is a progression from observation of a phenomenon, experimental process and the derivation of the mathematical equation or formalism (Ghassib 2012, 6-7). In contrast, the mathematical formalism or equations precede physical meaning at the postgraduate level. According to this view, the equations and formalism in general theory of relativity or quantum physics are set up prior to conveying physical meaning. The search for meaning starts after the introduction of the formalism. Experiments, philosophy and hypothesis are all utilised to discover the missing physical meaning (Ibid., 8). It is implied implies that in order to make this transition instruction at introductory level need to be built around empirical experiences to exhibit the nature of physical phenomenon. Progressively the relationship between physical phenomenon and mathematical equations and formalism need to be made explicit while moving to undergraduate levels. Having laid down strong foundation, instruction can centre on mathematical formalism at higher level.

Research in physics education offers a way to bridge the gap. It is argued that having laid down the foundation in experimental activity, meaning making and knowledge construction takes place through model-making process (various kinds of model-making). More importantly, model-making forms the bridge between experimentation and mathematisation. Without teaching model-making explicitly, physics instruction leaves a lot implicit in the relationship between the physical phenomenon and mathematical equations. Following the approach of mathematical modelling of experimental data, both, the physical interpretation of mathematical symbols and equations, and the process of mathematisation of physics can be illustrated and made explicit. Model-making is an intermediate process between concept formation and theory building. Taking the concept as the unit of the theoretical structure of physics is at the root of most of the problems students confront with physics instruction. In other words, rather than concepts, mathematical modeling should form the core in the organisation of physics instruction. As concepts are the constituents of models, it is automatically entailed in the process. Also, rather than network of concepts, problem-solving is essentially a network of model-building process. Thus shift from concept building to model-making process resolves the otherwise insoluble problem of 'problem solving' physics students have to confront (Hestenes 1987, 1996, 2006; Koponen et al. 2003; Halloun 2007; Kurki-Suonio 2010). Thus concurring with Gassib, this brand of PER proposes to make model-making as the core of introductory and undergraduate physics instruction. Having learned the approach (as to how mathematisation of physics takes place), the deductive approach should be followed thereafter.

In using the term 'phenomenological approach' Rakesh Popli (1999), though implicitly, extended the idea of 'concept experiment'. In his scheme, meticulously accurate experimental data when plotted graphically should lead to the mathematical equations taught in theory—a reversal of the traditional instructional approach. Other members of the IAPT fraternity limited themselves in expressing view on what could be advancement over traditional instruction. For instance, D. A. Desai (2004) argued that the lack of understanding of the mathematical equations and formalism in students is the result of the lack of exposure to rich experimental activities. Similarly the need to explicate the nature of modelling and mathematisation is expressed by others. Though there has been occasional mention, for example Joshi and Tillu (1989) or Gambhir, on model building process, it was not theorised and empirically tested in instructional setting by IAPT fraternity (Raman 1987, 33; Gambhir 2006, 342; Joshi 2003, 272). Similarly, without theoretical clarification, some of the members from West Bengal have suggested shift the use of experimental activity from concept-building to problem solving (for example Das et al. 2014; Samanta et al. 2014; Mandal et al. 2014). Both, S. C. Samanta and H. C. Verma have endorsed the proposal.[165]

What is the pedagogical perspective NSEP and NGPE offer? Physics examination, in IAPT's view, suffers from the predominance of factual questions. The bulk of the conceptual and problem-solving questions gets repetitive over the years and ceases to be representative of the whole gamut

[165] Samanta and Verma expressed their views at IAPT's annual conventions (2013) at Kolkata and Chandigarh (2014), respectively.

of physics learning. IAPT took initiative to rectify the problem by reducing the excess of the factual questions and adding the repertoire of conceptual and problem solving questions or experimental activities in NSEP and NGPE. Essentially the attempt is to make examinations more representatives in this respect. As far as pedagogical reconstruction is concerned examinations do not offer novel perspective. The examinations were comprehensive and well balanced in this sense and were represented by graphs, diagrams and data to be analysised and interpreted.[166] By creating requisite space for conceptual and problem solving questions or experimental activities in examination it happens to be a refinement act while being in didactic folds of pedagogy.

Unlike to NSEP and NGPE, concept inventories offer another perspective. Rather than certifying the level of students' mastery over the subject as is the case with NSEP and NGPE, objective of the concept inventory is to identify and diagnose the qualitative conceptual difficulty of the students.[167] Having furnished unambiguous data concepts inventories pave the ways for the development of what is called innovative instructional modules. Like concept inventories, their efficacy is scientifically validated (Meltzer and Thornton (2012). Though NSEP and NGPE were also intended to generate discussions and rectification of students' difficulties, it remained confined to the certification of what students have already learnt. As such running counter to what was actually intended; they do not provide scientifically validated account of the benchmark of examination reforms.

Furthermore, IAPT could only speculate to extend NSEP into preparatory examination for India's participation in International Physics Olympiad. Due to the lack of infrastructure and credible pedagogical work, it was not in a position to take steps ahead in this direction. On the other hand, HBCSE having committed in both of these fronts appears to be obvious choice for being given the responsibility to organise the examination. With financial

[166] Refer to appendix 2 on NSPE
[167] Subject id discussed in chapter 3

support from the government, it could undertake pedagogical reconstruction of the examination intensively.

The Nature of science (NOS) provides a symbiotic environment in which concepts are embedded and interconnected. The production of NOS material accordingly promises to enrich the understanding of concepts, laws and principles of physics and thus usher in a deeper understanding of physics (Posner et al. 1982; Matthews 1992; Duschl 2008). Though having produced a quantum of publications in this regard, IAPT members appear to be far from translating their work (on NOS) into a coherent framework. Also the publication on NOS has been decreased significantly over the years.

Chapter 7

Journal of Physics Education: A Bibliometric Analysis

7.1 Introduction

According to Pritchard (1969) bibliometrics is "the application of mathematical and statistical methods to books and other media of communication" (348). Putting it more lucidly Fairthorne defines bibliometrics as the "quantitative treatment of the properties of recorded discourse and behaviour appertaining to it" (1969/2005, 171). More recently, as Hérubel argues, bibiliometrics has also begun to map out the evolution of scholarly communities and exploring disciplinary cultures (Hérubel 1999, 381). Elaborating further he states, "Disciplinary formation, research trends, and the general specialized characteristics of scholarship can be illuminated for their intrinsic purposes or for a better understanding of how scholars and others disseminate their work," (Ibid., 385).

Bibliometrics happens to display a significant overlapping with sceintometric and in this sense sometimes appears to be quite indistinguishable from it. However, there are divergences between these two methodologies too. The focus of bibliometrics is on the measurement and analysis of the publications of scholarly literature. On the other hand scientometrics also takes up the analysis of the practice, policies and social, economic and developmental issues relating the field (Wilson as cited in Hood and Wilson 2001, 293). As research fronts have been continuously expanding scientometrics has begun to focus solely on science and technology (Hérubel 1999, 381).

As the study is concerned with the nature and trends of the publication appearing in the journal of *Physics Education*, the data extracted is subjected to bibliometric analysis. Two broader reasons determine the choice of the journal for analysis. [1] (1) The bulk of the literature published in the journal comes

[1] The Journal on Physics Education was launched by UGC in 1975. After going through the phases of successive closure and re-launching, the UGC assigned the Pune University

from Indian physics teachers and researchers spread across colleges and universities. Moreover it is not just the teachers but researchers from physics and allied disciplines who publish in the journal. Being the sub-set of the larger community of physics teachers and researchers not only from India but other countries as well, the nature of literature serves as an indicator of the research carried out by IAPT. (2) IAPT members directly or indirectly have been shaping the growth of the journal, especially after adopting the journal on 4 March, 2001 (IAPT 2001). The analysis covers publications spanning the period 1988-2010.

7.2 Thematic Categorisation and Bibiliometric Analysis

Considering the diversity of the literature published, the analysis of the publications is divided in three broad sections. The first section is divided into six sub-sections: This comprises: expository literature; reformulation of equations and research-teaching interface content; different versions of experiments from the sub-domains of secondary, undergraduate and post-graduate physics; computer applications in physics instruction; allied disciplines and technological fields; research on students' pre-scientific conceptions and proposals and reports on physics education. The second section deals with the institutional locations of the publications. Pedagogical interpretation of the literature is undertaken in the third section.

7.2.1 Exposition of Content

This genre of publications in the journal is of an expository nature, which means that they offer explanations, elaborations and illustrations of concepts or theories. They engage with specific problems in the textual material, prescribe the way it needs to be taught and address the conceptual difficulties

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the task of running the journal in 1984. After UGC withdrew support (while entering into 18th year of its existence) in 2001, IAPT came forward to take the responsibility of running the Journal of Physics Education. Following this, on 4 March, 2001, the association, as a part of its policy to promote useful work on physics education, adopted and decided to further upgrade the journal (IAPT 2001, 127). As a result, over the years, the journal has made steady progress and constitutes one of its major activities.

encountered by the readers (students and teachers). Publications are classified into the following themes.

Exposition of concepts (ECP): Besides the exposition of concepts, laws, and principles these publications explicitly address conceptual difficulties encountered by the readers (students and teachers). "Newton's Laws of Motions" and "Hermann-Bernoulli-Laplace-Hamilton-Runge-Lenz" are such examples from the introductory and postgraduate levels, respectively.[2]

Review of Concepts (RCP): Encompasses both historical and recent developments and applications of a concept, theory or an area of study. Rather than offering a detailed treatment of the theme being discussed it provides a general and broader review meant for teachers and students. For example, recent developments in Newton's Laws of Motion i. e. "Newton's Laws: possible modifications and consequences" and "Advances in the physics of quasi-crystals" (a form of crystal exhibiting long range five-fold symmetry or orientation order but no translational order--a deviation from the conventional ideas of crystallography discovered in 1984) are the examples of this type.[3]

History of concepts (HCP): Deals with the historical evolution of the concepts, theory and the contributions made by physicists. The literature entitled "The devices for the measurement of time and pre-relativity era in classical physics", "Brueckner and Bethe theory—classical Nuclear forces model,", "Maxwell's equations, electromagnetic waves and magnetic charges", "Optics: past and present" and "On the birth of Quantum Mechanics" are the

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[2] A. B. Datta, "Newton's Third Law of Motion," *Physics Education* 12, no. 3 (2009): 7-10.
B. Chakraborty, "Holonomic constraints in Classical Mechanics," *Physics Education 14, no.* 2 (1997): 169-174.
P. R. Subramaniam et al., "Hermann-Bernoulli-Laplace-Hamilton-Runge-Lenz," *Physics Education 7*, no. 4 (1991): 323-327.
[3] A. Ghosh, "Newton's Laws: possible modifications and consequences," *Physics Education* 11, no. 4 (1995*):* 417-425.
D. Bahadur and R. A. Dunlap, "Advances in the physics of Quasi-crystals," *Physics Education* 7, no. 2 (1990): 102-111.

example of this type. [4]

Textbook Problem Solving (TPS): The publications in this category comprise problem solving exercises that are often part of the coursework, for instance, "Worked out problems in work and energy in rectilinear motion".[5] These publications do not include the specific section meant for "problem solving". In this section readers are asked to solve the challenging problems posed to them. Though not tabulated for quantitative analysis, it is taken up for the pedagogical interpretation latter on in third section.

Reports on Teaching Activities (RTA): These are a series of articles reported and typically meant for teaching physics concepts well. For example, the titles such as -"Complex numbers, vectors and analytical geometry-tips from teachers" and "Teaching the concept of 4-dimension space-time via direct derivation of velocity addition formula" represents the example of RTA, respectively. [6]

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[4] M. Y. Anand and B. A. Kagali, "Measurement of Time," *Physics Education* 23, no. 4 (2007): 277-284.
R. Rajaraman, "Brueckner-Bethe theory," *Physics Education* 22, no. 2 (2005): 95-111.
U. D. Goswami, H. Nandan, C. P. Pandey, and N. M. Bezares-Roder, "Maxwellian Equation, electromagnetic waves and Magnetic changes," *Physics Education* 25, no. 4 (2008): 252-265.
C. P. Singh, "On the birth of Quantum Mechanics," *Physics Education* 8, no. 1 (1991): 5-14.
[5] S. Datta, "Worked out problems in work and energy in rectilinear motion," *Physics Education* 27, no. 3 (2010): 165-183.
[6] A. W. Joshi, "Complex numbers, vectors and analytical geometry," *Physics Education 15*, no. 2 (1990): 127-129.
H. I. Zhang, "Teaching the concept of 4-dimentional space-time via direct derivation of velocity addition formula," *Physics Education* 9, no. 1 (1992): 40-43.

Table 7.1 Quantitative distribution publications under 'Exposition of Content'

Domains	ECP	RCP	HCP	TPS	RTA	Total
Classical mechanics	10	-	3	2	-	15
Heat-Thermodynamics	-	-	1	-	-	01
Waves and Oscillations	3	9	5	1	-	18
Atomic Physics	4	-	2	-	-	06
Electromagnetism	8	-	2	-	-	10
Electrodynamics	-	1	-	-	-	01
Electronics	3	-	-	-	-	03
Optics	-	-	1	-	1	02
Special and General theory of relativity	15	4	-	-	2	21
Astrophysics	42	5	2	-	-	49
Electro Optics	3	1	-	-	-	04
Photonics	1	-	-	-	-	01
Laser Physics	7	-	-	-	-	07
Quantum Physics	35	2	1	5	2	45
Statistical Physics	8	-	-	-	-	08
Plasma Physics	1	-	-	-	-	01
Nano- Science	19	-	-	-	-	19
Solid State Physics	4	-	-	-	-	04
Spectroscopy	6	-	-	-	-	06
Micro and Interferometry	6	-	-	-	-	06
High Energy Physics	23	-	5	-	-	28
Mathematical Physics	4	-	-	-	-	04
Total	202	22	22	8	5	259

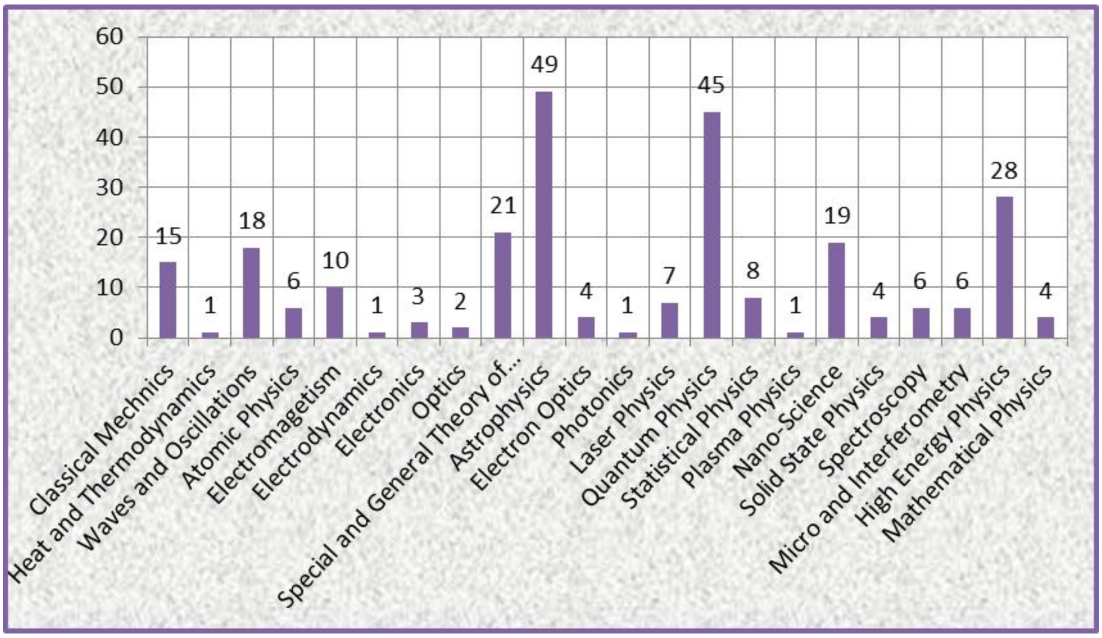

Figure 7.1 Domain wise publications under the 'Exposition of Content'

As shown in the graph, the number of publications in astrophysics (49), quantum physics (45) and high energy physics (28) are substantially higher. This is followed by nano-science (19), theory of relativity (19), waves and oscillations (18) and classical mechanics (15), respectively. At other extreme, there is just 1 publication in the areas of photonics, plasma physics, and electronics respectively.

Being highly active area of research, large array of concepts have emerged in astrophysics for last several decades. A segment of them is already part of the curriculum at different levels and absorption of the other ones is in process. Significantly high frequency of the publications in this domain reflects this trend. Same reason appears to hold true for high energy physics and nano-science. Thrust on the exposition of the foundational concepts and counter-intuitive nature of quantum physics is the reason for its receiving relatively higher amount of publication. A bulk of these publications is devoted to address conceptual difficulties faced by the students. Clearly the amount of publication is skewed in favour of higher physics.

At the introductory level, publications in classical mechanics have received are highest in number followed by electromagnetism (15), waves and oscillation (8) and thermodynamics (8) and optics (6), respectively. What is the reason behind higher frequency of the publication in electromagnetism? Is a perception of the difficult nature of electromagnetism the reason for getting higher publication frequency? What about other domains? No data is available to draw conclusions on this issue.

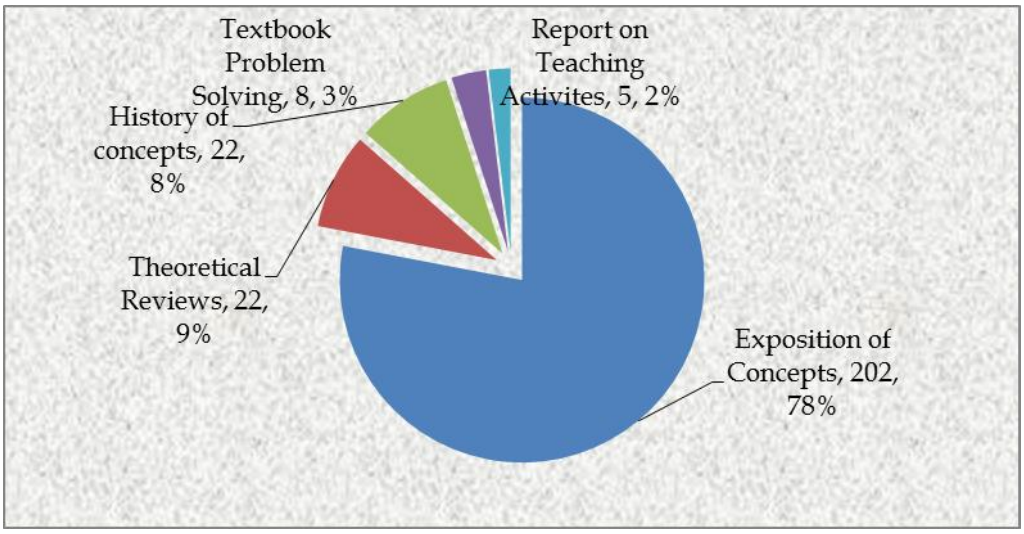

Figure 7.2 Percentage of the sub-categories under 'Exposition of Content'

As shown in the figure, publication under 'conceptual exposition' is highest among different sub-categories (78%). This is followed by the history of concepts (8%), review of concepts' (9%) and textbook problem solving (3%), respectively. As exposition of concepts is predominantly carried out in the curricular and instructional process, it is not unexpected to get the bulk of the publications in this category.

7.2.2 Reformulation of Equations (RE) and Research-Teaching Interface (RTI)

A significant number of publications address the reformulation of mathematical equation, inter-domain synthesis of concepts, investigative studies, review of research and research techniques. The quantum of literature spans introductory, undergraduate and post-graduate physics. The thematic classification is given below.

Derivation of Physics Equations (DPE): This involves alternative formulations or the reconceptualization of physics equations. The 'exposition of content', exposition involves both qualitative and quantitative elaboration of concepts, this category deals exclusively with the alternative or novel derivation of mathematical equations. The article—"Speed of efflux for viscous liquids" provides a theoretical analysis and formulation of mathematical relations relating the effect of viscosity and size of opening on the pressure within the fluid. Similarly, "Lens-maker's Formula Revisited" deduces the respective formula in an alternative way or "A simple method for solution of Time-independent Schrödinger Equation with confining Potential" solves Schrodinger's equation through an approximation.[7]

Inter-domain conceptual synthesis (IDCS): These publications offer a comparative analysis and integration of the concepts across classical mechanics, relativity and quantum physics. Examples include "Subjecting Newton's laws to gauge and symmetry transformations", "Perturbation theory" or "The wave-packet in a gravitation field".[8]

Investigative Study (ISD): Comprises the empirical investigations of physical problems at introductory, undergraduate, post graduate level and research levels involving both theory and experiment. As such it differs from the themes- 'Derivation of Physics Equation' and 'Experiment'. Publications include "A simple understanding of the distribution of acoustic relaxation

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[7] I. Eghuanoye, "Speed of efflux for viscous liquids," *Physics Education* 7, no. 1(1990): 16-18.
J. B. Karnik and H. C. Pradhan, "Lens-maker's Formula Revisited," *Physics Education* 9, no 1 (1992): 5-9.
U. Laha and B. Kundu, "A simple method for solution of Time-independent Schrodinger Equation with confining Potential," *Physics Education* 26, no. 1 (2009): 35-39.
[8] S. Bharve, "A local gauge symmetry of Newton's Law," *Physics Education* 8, no. 2 (1991): 148-152.
N. Inui, "Galileo's Gedanken experiment on free fall of Quantum objects," *Physics Education* 24, no. 1 (2007): 59-66.

times in some organic liquids" and "A study of phase and group velocities using waves".[9]

Review of Researches (RVR): These publications include a review of current research studies, laboratory techniques, research facilities and scientific instruments. Their focus is distinct from the 'review of concepts' (RCP). Here the purpose is to facilitate the absorption and consolidation of the newly emerged literature for instructional purpose rather than enhancing the exposition of the content already part of the curriculum. For instance, advancements made in regard to the semiconductor, explorations into nature of processes occurring in the Sun and Auger Electron Spectroscopy fall under this thematic category.[10] Some of the reviews are about the applicability of mathematical techniques in research problems. For example, "Solutions of Confluent hyper-geometric function" is meant to provide the solutions for the linear harmonic oscillator, hydrogen atom and three-dimensional isotropic oscillator in quantum mechanics.[11]

Research Techniques (RT): These publications deal with the exposition of scientific instruments, experiment or a method used at the interface of research and teaching. For example, researches on the changes in nuclear shapes at high angular momentum and elemental analysis.[12]

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[9] A. V. Narsimahm, (1991). "A simple understanding of the distribution of acoustic relaxation times in some organic liquids," *Physics Education* 8, no. 2 (1991): 96-101.
G. S. Pillai, V. K. Vaidyan and C Kartha, "A study of phase and group velocities using waves," *Physics Education* 12, no. 2 (1995): 168-173.
G. Dissanaike, "Sunrise from high altitude in clear and polluted skies," *Physics Education* 19, no. 3 (2002): 257-262.
B. C. Rai and H. C. Verma, "Quantum statistical charge distribution HCP Metals," *Physics Education* 11, no 4(1995): 406-411.
[10] A. Pimpale, "Recombination of electrons and holes in semiconductors," *Physics Education* 15, no. 4 (1999): 307-322.
A. W. Joshi, "Studying the Sun-a challenging space adventure," *Physics Education* 8, no 2 (1991): 118-127.
S. K. Kulkarni, "Auger Electron Spectroscopy," *Physics Education* 9, no. 2 (1992): 145-151.
[11] A. K. Ghatak and I. C. Goyal, "Use of Confluent hyper-geometric function in Quantum Mechanics and waveguide theory," *Physics Education* 20, no. 2-3 (2003): 115-126.
[12] R. K. Bhowmik, "Nuclear shapes at high angular momentum," *Physics Education* 11, no. 4 (1995): 370-376.

Table 7.2 Quantitative distribution of the publications on RE and RTI

Domains	DPE	IDCS	ISD	RVR	RT	Total
Classical Mechanics	6	7	-	-	-	13
Heat and Thermodynamics	8	-	-	-	-	8
Waves and Oscillations	1	-	7	-	-	8
Electromagnetism	9	-	-	-	-	9
Electrodynamics	3	-	-	-	-	3
Electronics	-	-	-	2	-	2
Optics	1	-	5	-	-	6
Photonics	-	-	1	1	-	2
Special and General Theory of Relativity	-	1	-	-	-	1
Astrophysics	-	-	2	10	-	12
Quantum Physics	2	10	1	-	3	16
Statistical Physics	-	-	1	1	-	2
Solid State Physics	1	-	4	-	2	7
Nano-Science	-	-	-	5	6	11
Spectroscopy	1	-	-	-	11	12
High Energy Physics	-	-	-	7	11	18
Mathematical Physics	-	-	-	3	-	3
Total	32	18	21	29	33	133

V. Khole, "Element analysis using X-ray fluorescence technique with synchrotron radiation," *Physics Education* 8, no. 1 (1991): 57-64.

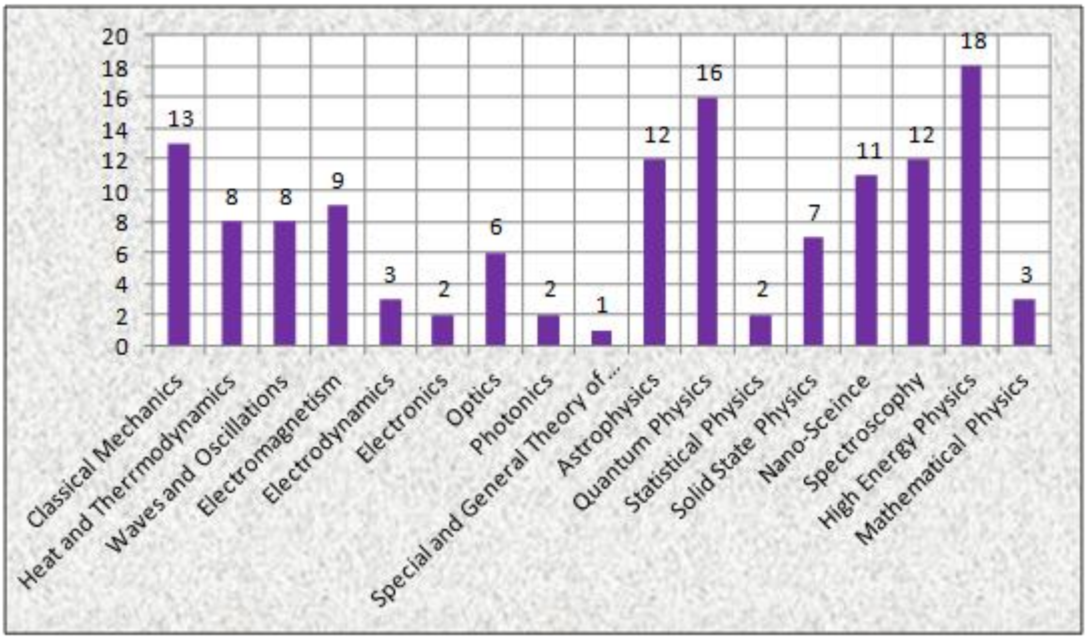

Figure 7.3 Domain wise publications on RE and RTI

As displayed in the graph, highest number of publications is from high energy physics (18), followed by quantum physics (17), astrophysics (12), spectroscopy (12), nano-science (11), electronics (9) and heat and thermodynamics (8), respectively. Relatively higher number of publication is on the derivation of physics equation and has come from the undergraduate and introductory physics than post-graduation. Investigative studies have been undertaken at all of these levels of physics education. Inter-synthesis of concepts has taken across the mechanics, quantum mechanics and theory of relativity. Most of the publications on review of researches and research techniques have come from higher physics.

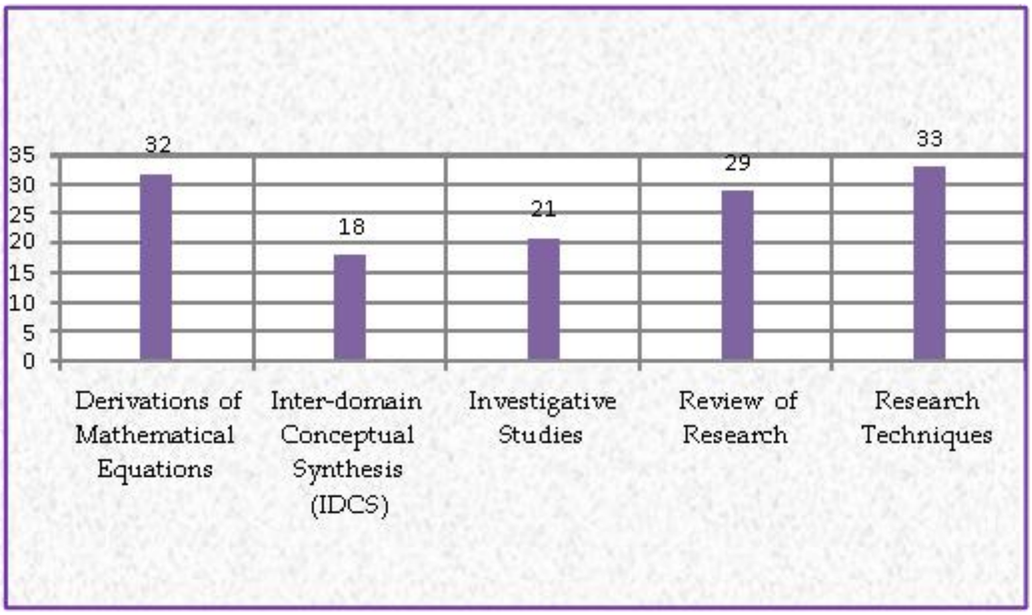

Figure 7.4 Quantitative distribution of RE and RTI

Clearly, the maximum number of publications falls under the category of research and teaching interface (33), followed by derivation of physics equations (32), review of research (29), investigative studies (21) and inter-domain conceptual synthesis (18), respectively. Apparently significantly amount of content evolving out of the researches in different domains over a span of time has find a way into the publications implied to be absorbed in instructional and research purpose.

7.2.3 Development and Testing of Experiments

Publications in this category aim to add to the repertoire of experiments that are part of introductory, undergraduate and post-graduate curricula. They are developed at the school, college, university and other laboratory sites such as Indian National Physics Olympiad (INPOpiad), Indian Institute of Science Education and Research (IISER) and NCERT etc. A few of these experiments are explicitly meant for the development of concepts under the head of "Teaching Physical Concepts through Laboratory" and "Physics through Experiments". Explicitly, the objective is to shift the role of experiment from verification of theory or determination of physical constants to the development of concepts. The placement of the publications under different headings is as per the actual terms used in the abstracts and the content of the respective publications. The definition of these categories is given below.

Experiments (EXP): These publications deal with the quantitative measurement and verification of physical quantities and are the outgrowth of individual or group efforts such as that undertaken at the Indian National Physics Olympiad. These also include reports on the experiments employing alternative methods and include the determination of Boltzman's Constant, oscillatory behavior of a complex object such as sectioned sphere, power loss due to heat, and demonstration of the non-linear dynamics of a simple pendulum when oscillations are allowed to enlarge.[13]

Demonstration (DM): These publications deal with experiments devised for the qualitative demonstration of concepts in the classroom. For example, typical titles of publications in this category are: "Reduced mass of two-body system using a linear track simulates the vibration of the diatomic molecule" and "Diffraction demonstration apparatus" are meant to demonstrate a concept.[14]

Improvisation (IMP): This deals with experiments devised by using cost-effective, no-cost or readily available material. For example the publications are entitled: "Reduction of friction through a record player and a spinning projectile", and "Optical activity of transparent Cello-phone films".[15]

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[13] K. I. Jat and G. Sharma, "Determination of Boltzmann constant by an ordinary P-N Diode," *Physics Education* 13, no. 4 (1997): 377-381.
C. B. Joshi, (1993). "Oscillatory, Behaviour of a Sectioned Sphere," *Physics Education* 10, no. 2 (1993): 167-170.
S. R. Pathare, R. D. Lahane, S. S. Sawant and C. C. Patil, (2010)."Power loss from hot tungsten filament," *Physics Education* 27, no.2 (2010): 111-126.
P. Arun and N. Gaur, "How simple is simple pendulum," *Physics Education* 19, no. 3 (2002): 185-191.
[14] V. D. Lalchandani, "A simple set-up for demonstration of Lissajous Figure and Beats," *Physics Education* 17, no. 2 (2000): 151-154.
V. D. Lalchandhani and U. Singh, "Diffraction demonstration apparatus," *Physics Education* 16, no. 4 (1994): 373-376.
[15] H. C. Verma, "Learning about atmospheric pressure using injection syringes, "*Physics Education 22, no.* 3 (2005): 191-194.

Physics Teaching through Laboratory (PTL) and Teaching Concepts through Laboratory (TCL): These publications report teaching concepts through experiments or demonstrations. One of the first publications in this category dates back to 1995 on the "Variation in the period of simple pendulum with amplitude".[16]

Design and Fabrication (DN/FB) of experiments: These include reports on the experiments designed or involve fabrication of an experimental set-up, such as "Fabrication of a simple beta ray spectrometer" and "A rich-field-cum-high resolution Newtonian Telescope".[17] Teachers have personally involved in the design and fabrication of these experiments and required to have sophistication in constructional skills. In some cases their efficacy is tested in the classroom.

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[16] N. R. Bhamare and D P Khandelwal, " On the planning of a teaching laboratory-experiment 1: variation in the period of simple pendulum with amplitude," *Physics Education* 12, 2 (1995):174-177.

[17] M. B. Singh, B. Singh and S. Singh, "Fabrication of a simple beta ray spectrometer," *Physics Education* 14, no. 3 (1997): 263-268.
Ved. Ratna, "A rich-field-cum-high-resolution Newtonian telescope," *Physics Education* 11, no. 2 (1994): 131-135.

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Table 7.3 Quantitative distribution of Experiments and PTL/TCL

Typology / Domains	EXP	DM	IMP	DN/FB	PTL/TCL	Total
Classical Mechanics	9	4	-	-	-	13
Waves & Oscillations	-	2	-	-	2	04
Heat & Thermodynamics	4	-	1	1	-	06
Atomic Physics	-	-	-	-	2	02
Electromagnetism	28	-	-	-	-	28
Electronics	9	-	-	-	-	09
Optics	8	-	1	4	1	14
Mathematical Physics	-	-	-	-	2	02
Solar System	3	-	-	-	-	03
Plasma Physics	7	-	-	1	-	08
Solid State Physics	3	-	1	1	-	05
Spectroscopy	2	-	1	1	-	04
Micro and Inter-ferometry	-	-	-	1	-	01
Total	73	6	4	9	7	99

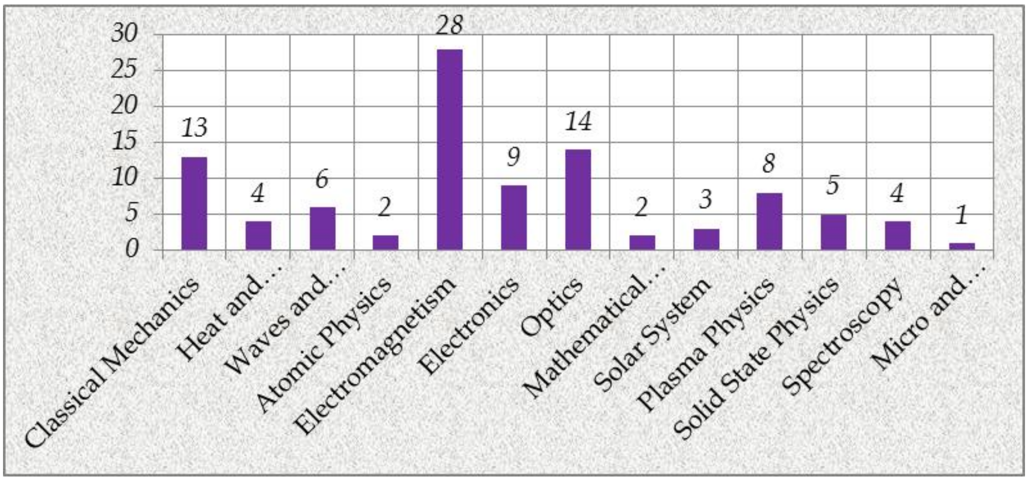

Figure 7.5 Domain wise publications of Experiments and PTL/TCL

Clearly a significantly higher number of publications are from electromagnetism (28), followed by optics (14) and classical mechanics (13), electronics (9) and plasma physics (8), respectively. Publications from other domains are comparatively very low in number. The day today life experience of the students runs counter to the electromagnetic phenomenon they encounter are counter intuitive in nature and therefore difficult to comprehend. Exhibition of electromagnetic phenomenon by performing experiments and demonstrations not only remedies the problem to significant extent but also makes it appealing and interesting. Similar argument can be extended for receiving a greater number of experiments and observations in optics.

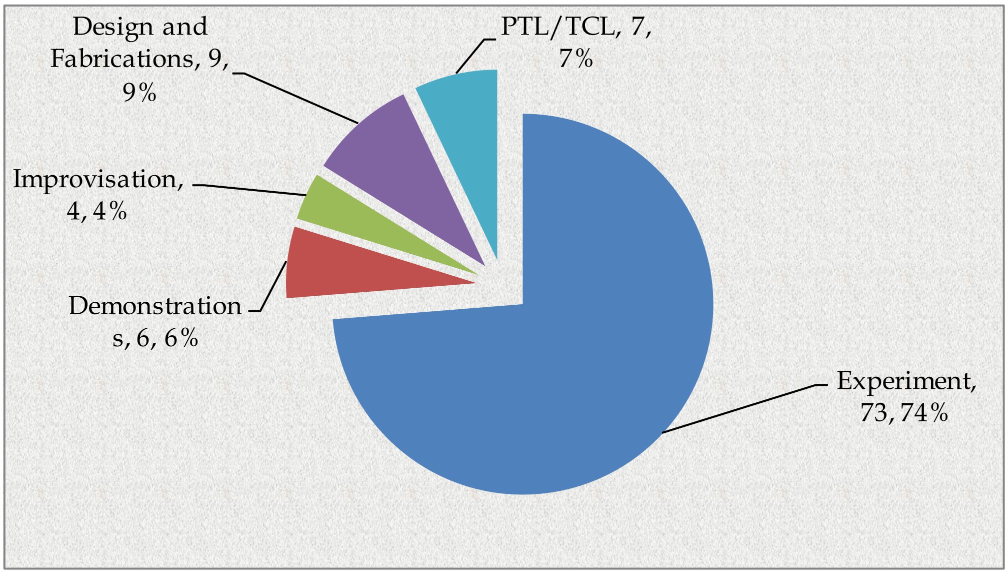

Figure 7.6 Percentage distributions of Experiments and PTL/TCL

As revealed in the pi-chart above, the share of the publications of manual experiments is comparatively much higher (74%) than the other categories. The share of design and fabrications, PTL and TCL, demonstration and improvisations is 9%, 7%, 6% and 4%, respectively. Teachers seem to be more engaged in constructing experiments and have not extended their work to demonstrations and improvisations significantly.

7.2.4 Computer Application in Physics Instruction

Though beginning around 1980, application of computer technology in the renewal of experimental work and presentation of data became an integral part of science and physics education during end of the decade (Wilson and Redish 1989). Thematic classification of the categories under this head is given below.

Computer-interfaced Experiment (CIE): Inter-facing of computers with manually guided experiments is referred to as 'Computer-interfaced Experiment'. A computer-interfaced experiment setup is comprised of the experimental apparatus or equipment, sensors to measure, control and alter the physical parameters; and recording and display subsystems to handle the generated data. The facility for the rapid extraction and portrayal of the detailed and finer data, and that too with a fast pace, makes it conducive to delve deeper into the nature of the physical phenomenon being studied. As a result, it is claimed to have pedagogical advantage over manual experiments.

Computer Simulation (CS): A computer simulation is a visual and dynamic model of physics concepts, processes or experiments presented on a computer screen. Due to the visual representation, it has a pedagogical advantage over mere verbal description and explanation. Computer simulations enhance the conceptualisation of the phenomenon by engaging students interactively with visual representation of a phenomenon or data in a model. Moreover, it has the added advantage when a laboratory is not available either due to financial problems or some sort of danger involved in performing the experiment. However, being a virtual representation, computer simulation has its limitations and cannot be a replacement for real physical phenomenon. Students need to realize and critically examine the assumptions upon which the simulations are designed.

Computer Mathematics and Graphics (CMG): Refers to the presentation of mathematical derivations and formalism in conjunction with graphical simulations. A few of the publications dealing exclusively with the mathematical derivation are also dealt in this category. The presentation of mathematical derivations and problem solving through computers eases the teachers' drudgery of black-board work and leaves space for the other teaching activity. As such it helps overcome the fixity of the visual presentation associated with mathematical derivation and formalism. This is more so when there is a focus on animation, interactivity and three dimensional representations. This helps student deal with the abstraction inherent in the mathematisation of physics.

Table 7.4 Domain wise publications in computer application in physics education

Domains	**CS**	**CMG**	**CIE**	**Total**
Classical mechanics	3	1	-	4
Heat-Thermodynamics	1	1	2	4
Atomic Physics	1	-	-	1
Waves and Oscillations	-	-	3	3
Electromagnetism	1	-	2	3
Electronics	-	1	7	8
Optics	1	1	1	3
Astrophysics	2	-	-	2
Quantum Physics	3	1	-	4
Statistical Physics	-	2	-	2
Solid State Physics	-	-	3	3
High Energy Physics	1	-	1	2
Mathematical Physics	2	6	-	8
Multi-disciplinary	-	-	6	6
Total	15	13	25	53

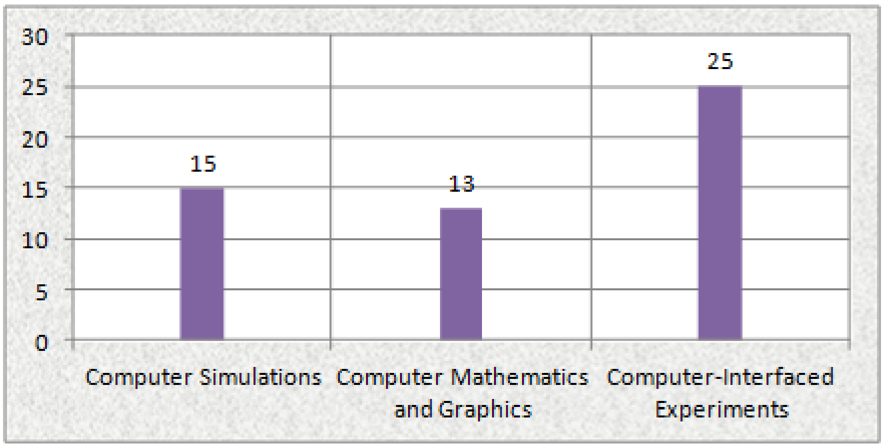

Figure 7.7 Publications in computer applications in physics education

As shown in the graph, computer-interfaced experiments have highest frequency (25) of publications followed by computer simulations (15) and mathematical and graphics presentation by computers (13). Onset of computer application has found a way into the experimental activity in instructional process at senior secondary and tertiary stages from around 1990s and has been gathering momentum since then (Trumper 2003). In India momentum picked up in the second half of 1990 and presentation of large number of computer-interfaced experiments at Annual National Convention of IAPT during 2001 appears to be a consequence of this (Samanta 2001)

7.2.5 Allied Science Disciplines and Technological Fields

Since its inception in 1984, in addition to physics, the journal also promoted literature from allied disciplines and technological fields.[18] This section deals

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[18] The intended readers and the nature of subject matter for the journal are reproduced from the year 2009-2010. With some minor changes, the terms and conditions for the inclusion of subject matter have been reproduced by the editors as laid down during 1988. The added words are marked in italics:
"SUBJECT COVERAGE: The journal deals with education and studies in physics at the level of *secondary*, undergraduate and postgraduate studies in physics in Indian universities. The scope of the journal is wide and it would contain articles, *news, notes, letters, comments* that may be of interest not only physics students but also to students from chemistry, mathematics, engineering and other allied disciplines. It is also expected to provide a forum for teachers of physics in *secondary schools*, colleges and universities and other institutes of higher education. The journal publishes articles in the following categories:
(1) *Matter* which is explicitly educational, that is detailed or of pedagogical in nature on particular topics in physics or relating to methods of teaching physics in classroom and

with the analysis of the literature received in these areas. The sub-categories under these are same as those employed in the first two sections.

Allied Science disciplines inclued inter-disciplinary areas where physics is one of the contributing disciplines. In other words, the term 'allied discipline' is used for the disciplines sharing boundaries with physics (refer to the footnote [no. 230] below). The literature in Atmospheric Science, Bio-Physics, Chemistry, Material Science, Geo-physics, Health, and Physiology falls under this category. Publications under Technological fields cover a wide spectrum of sub-domains like information technology, metallurgy, energy, remote sensing, radiology, electronics etc.

Table 7.5 Distribution of publications in Allied disciplines and Technological fields

Allied Domain	**ECP**	**HCP**	**EXP**	**ISD**	**RVR**	**RT**	**Total**
Atmospheric Science	5	-	-	5	1	-	11
Bio-physics	3	1	1	1	1	3	10
Chemistry	2	-	-	1	-	3	6
Material Science	2	-	-	2	1	-	5
Geo-physics	4	-	-	1	-	-	5
Physiology	2	-	-	1	3	-	6
Health Hazards	1	-	-	1	-	-	2
Technological fields	26	-	-	-	-	-	26
Total	45	1	1	12	6	6	71

laboratory.
(2) *Matter* of reflective nature that bear on fundamentals of physics or that offer new insights into known phenomenon in physics.
(3) *Matter* of crossing boundaries between physics and other scientific disciplines, articles on social and cultural implications of physics."

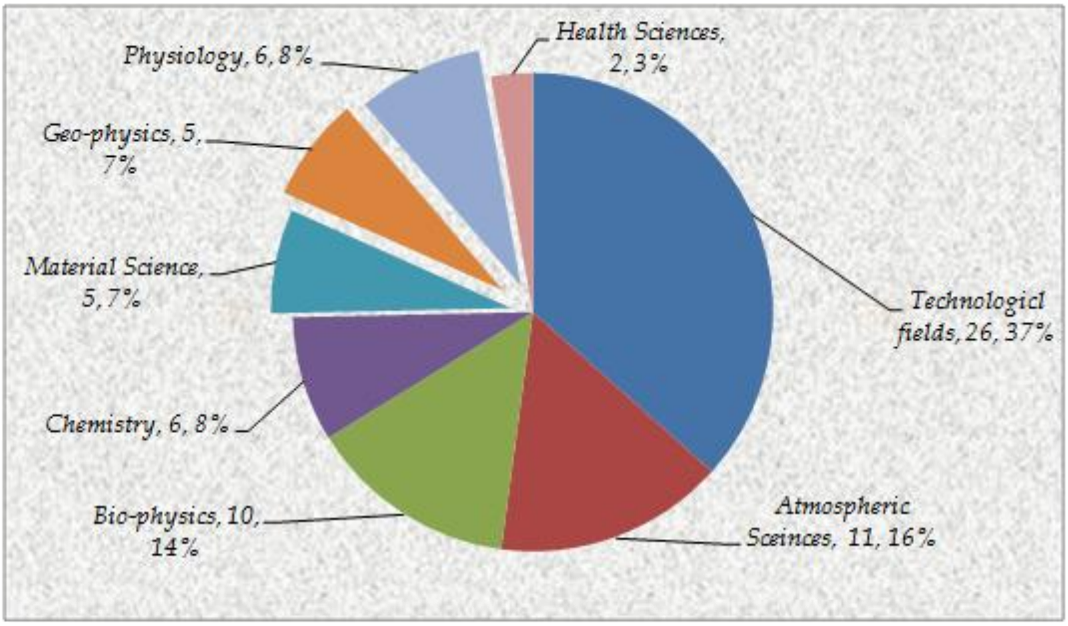

Figure 7.8 Percentage distribution of literature in Allied disciplines and Technological fields

As evident from the pie-chart, the quantum of publication in atmospheric science is highest (11 or 6%) amongst allied domains followed by biophysics (10) and chemistry (6) etc. Publications under Technological fields are the highest in number (26 or 37%) and cover a wide spectrum of sub-domains (not shown in the table above) like information technology (6), medicine (7), Industry (2), food technology (2), and radiology, remote sensing, earth quake forecasting, energy molecular electronics 1 each. Some of them are synthesis of different areas and are termed as inter-technological domain (3). Apparently, these publications comprise of the application of physics knowledge and add to the knowledge repertoire of the readers.

7.2.6 Physics Education

This section deals with the publications entitled 'Reports of activities on Physics Education', 'Pedagogical Reflections', 'Physics Education Research' (PER) as well as 'Extra-disciplinary Topics' in philosophy, psychology etc. Only thematic categories having specific meaning are given below.

Physics Education Research (PER): Are the publication on systematic probe into the nature of students' pre-scientific conceptions, for example, Maxwell's displacement-current. Additionally, it consists of scientific documentation of problem-solving by students. Problem-solving refers to the use of conceptual and procedural knowledge students employ to solve problems in physics.

Computer-assisted Teaching: Refers to the inclusion of multimedia instructional formats, such as animation, video and simulation, and virtual learning environment WebCT and Blackboard.[19]

Testing the Effectiveness of an Alternative Teaching Method**:** Introduction of a new mode of content transaction in the classroom is termed as 'alternative teaching method'. In order to test the effectiveness or its merit over the traditional method, the overall classroom environment is kept invariably same as the traditional one.

Nature of Time: Is a series of papers addressing various facets and paradoxes related to the nature of time in philosophy, Newtonian mechanics, relativity, thermodynamics and cosmology etc.

The following table provides the quantitative distribution of various thematic categories falling under each of these heads. 'F' symbolizes the frequencies of the thematic categories falling under each of the sub-heads and is provided in the right side of the thematic categories in the table below.

[19] WebCT is an eLearning platform that allows educational institutions to create and host courses on the Internet. Courses created with WebCT can serve as entire online courses or as a supplement to traditional classroom courses. Source: http://www.cuhk.edu.hk/eLearning/c_systems/webct6/

Table 7.6 Publications under Physics Education

Proposals and Reports on Physics Education		**Pedagogical Reflections**		**PER**		**Extra-disciplinary Publication**	
Typology	**F**	**Typology**	**F**	**Typology**	**F**	**Typology**	**F**
(Proposals/Analysis of programmes and policy/status reports)	21	Mathematical Formalism	3	Alternative conceptions (PER)	13	Relation of physics with other areas of life	9
Reports of workshops conducted	5	History of physics	1	Problem solving (PER)	2	Nature of time	10
Curricular reports/proposals	7	Language of physics	1	Computer-aided teaching	2	Indian Philosophy	2
Evaluation tools/techniques	3	Conceptual Learning	1	Efficacy of a teaching method	6	Cognitive science	2
---	---	Experiments	9	Correlational of two teaching methods	4	---	---
---	---	Science Museum	1	---		---	---
---	---	Digital Laboratory	2	---		---	---
---	---	Computer Simulation	1	---	-	---	---
---	---	Problem Solving	2	---	-	---	---
---	---	Miscellaneous	3	---	-	---	---
Total	36		24	-	27		23

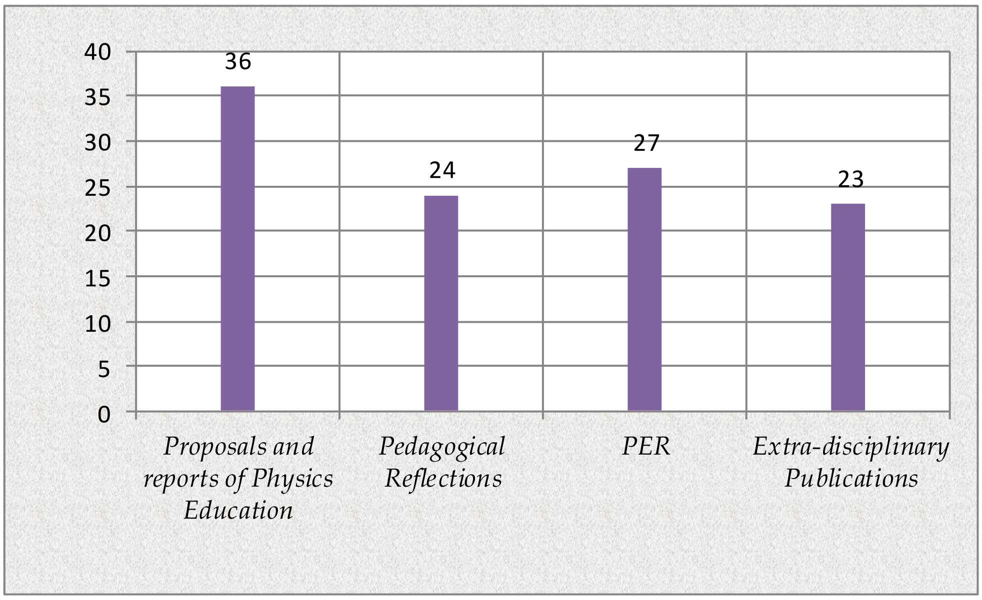

Figure 7.9 Categories of publications under physics education

The analysis reveals the maximum number of publications belong to 'Proposals and Reports on Physics Education' (36) and followed by PER (27), pedagogical reflections (24) and extra-disciplinary publications. When compared to overall publication, the share of PER comes out is (3.72%) and mostly limited to the identification of pre-scientific conceptions and testing the effectiveness of some teaching method. Virtually all the publications (25 out of 27) in this domain have come from the Departments of Education or Homi Bhabha Centre for Science Education. Does this suggest that PER has not made inroads into physics departments in colleges and universities in across India? The authorship pattern of the publication seems to suggest so. However, in the absence of literature from other source and journals, it is premature to arrive at this conclusion.

7.3 Institutional Sites of the Publications

The journal of *Physics Education* is meant to provide a platform to physics teachers, researchers, students and the others working for the upgradation of physics education. How is the affiliation of the authors distributed across the states and institutions in India and in other countries? The identification of the quantitative pattern can throw light on the concern and involvement of the authors in the renewal of physics education in the country. The authors are affiliated to physics departments of colleges and universities, engineering colleges, research institutes, department of education or science education. The authors are situated in India and many other countries across the world. The publications from these institutional locations across India and other countries are tabulated below.[20]

Table 7.7 Share of Indian States and other countries in the publications

Indian State/Institutions/Foreign Country	University Departments	Colleges	Engineering Colleges and poly	Research Institute	Inter-Institutional Collaboration	Physics Education Departments	Miscellaneous Publications	Total
Andhra Pradesh	5	1	1	4	-	-	-	11
Assam	7	-	2	1	-	-	-	10
Gujarat	6	1	1	11	-	-	3	22
Karnataka	2	1	-	15	-	1	-	19
Kerala	8	6	-	1	-	-	-	15
Madhya Pradesh	7	5	-	17	-	-	-	29
Maharashtra	150	42	3	49	4	48	10	30 6
Orissa	10	3	4	-	-	-	-	17
Pondicherry	6	-	1	-	-	-	-	7
Punjab	5	1	9	1	1	-	-	17
Rajasthan	4	1	-	-	-	-	2	7
Tamil Nadu	22	2	1	9	-	-	-	34

Continuation of the Table

[20] The journal from time to time has been asking its readers to solve the challenging problems posed to them in a special section devoted to it. The publication stablished from 2001. These publications were not tabulated earlier for the reason that the nature of these publications is pretty obvious—their structure is like the textbook version of problem solving and no new insight is offered regading the nature and structure of problem solving beyond posing the problem and offering solutions. Consequently, the total tally of the publications increases (from 725) to 799 as shown below.

Telangana	6-	-	2	-	-	-	-	8
Uttarakhand	1	1	-	5	-	-	-	7
Utter Pradesh	26	-	2	-	-	1	7	36
West Bengal	5	35	1	11	-	1	-	53
NCERT & Regional Colleges	-	-	-	-	-	41	-	41
IIT's/ISSERs	53	-	-	-	-	-	-	53
Foreign Countries	62	-	3	-	1	2	28	96
Left over	11	-	-	-	-	-	-	11
Total	396	99	30	124	6	94	50	799

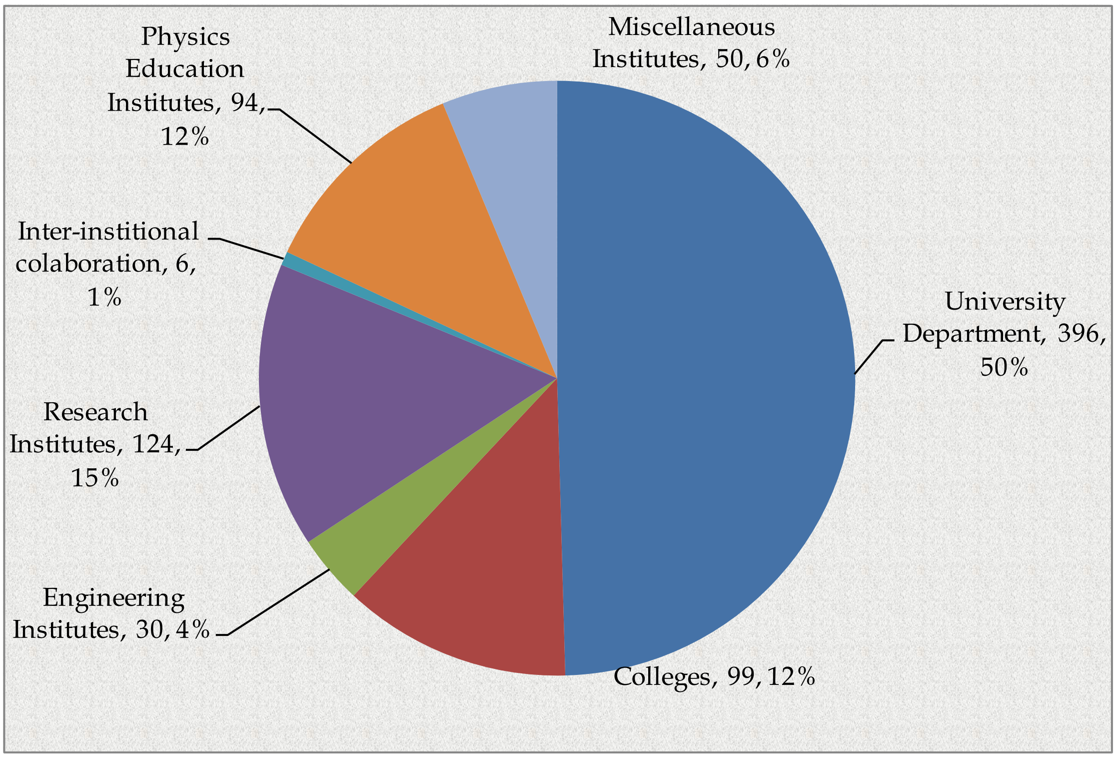

Figure 7.10 Percentage of publication of different kinds of institutions

As shown in the pi-chart above, the largest percentage (50%) of publications are authored by faculty from physics departments in the universities followed by faculty from research institutions (15%), colleges (12%), department of education or science education institutes. 6% publications are miscellaneous in nature, while 4% and 1% of them have come from the engineering institutes and as a result of the collaborative work of the author from different institutions. Being at the top of the hierarchy, it appears that leadership has come from the university departments in initiating and sustaining the publication work in the journal. This trend is also reflected by in the authorship coming from the research institutions. Though, teachers at undergraduate level (both B.Sc. and Engineering) are mostly engaged in teaching. Though their numbers are large they do not figure proportionately in the number of publications.

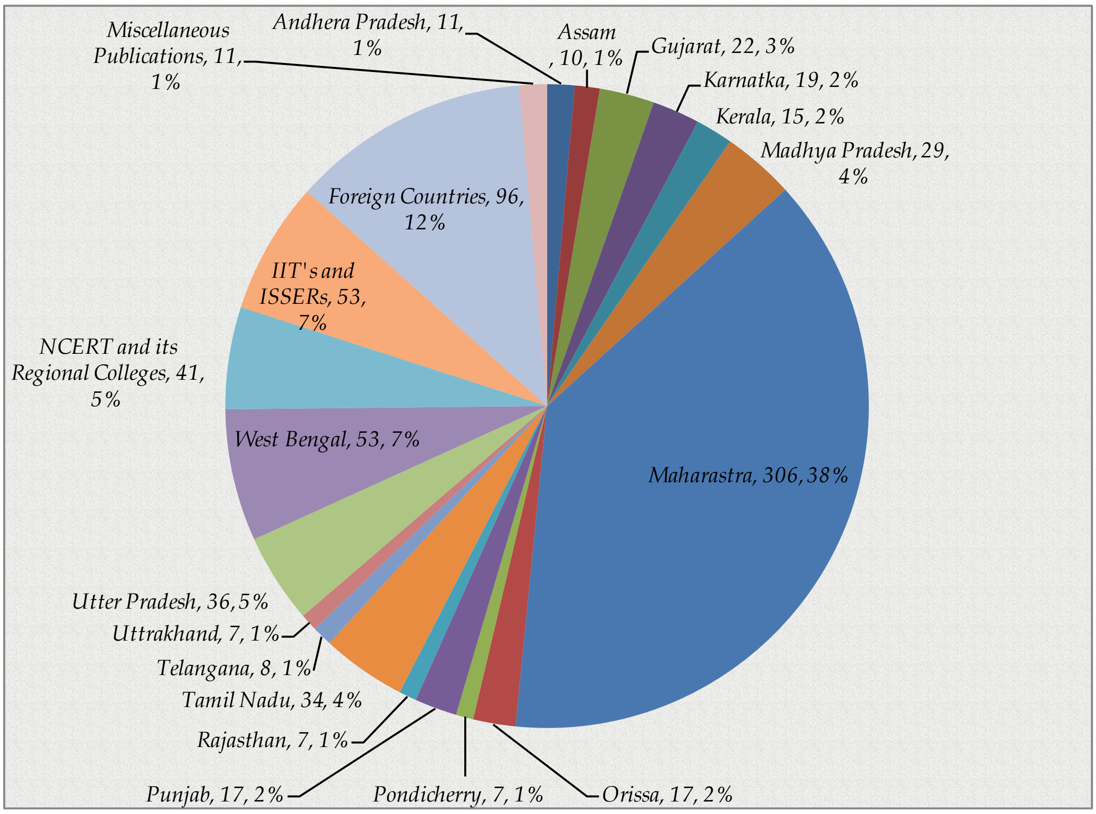

Figure 7.11 Share of Indian States and other countries in the publications

It is notable that the share in the publication from the state of Maharashtra (Universities of Pune, Nagpur and Thane etc) (38%) are significantly higher than the other states. This is followed by the West Bengal (7%) and Indian Institutes of Technologies (IITs) (7%). As a whole, the contribution from other countries is 12%. It is recalled that UGC assigned the Department of Physics, Pune University editorial responsibility for the journal in year 1984. This possibly explains the higher number of publications from the universities in Maharashtra and more so from Pune University itself (as a whole 26% of the publications).

7.4 Remarks on the Pedagogy of Physics

The section takes up the pedagogical interpretation of the literature appearing in the publications.

7.4.1 Expository literature

In the sequence of discussion that follows, similar examples are clubbed together.

1. Newton's Laws of Motion pose conceptual difficulties for a large numbers of students. For instance, Newton's Third Law of Motion' clarifies the concept as well as widens the application of the law.[21]

   The concepts in physics are overwhelmingly represented in quantitative or mathematical form. Providing clear and sufficient qualitative description of the phenomenon complimenting mathematical expression remains underrepresented. The lopsided treatment, according to the author of the article entitled "On the Joule's Law' becomes a source of major conceptual difficulties for the students. Joule's Law represents the equivalence of the mechanical work and heat or conversion of mechanical energy into heat and vice versa. By giving qualitative description of the random collisions taking place amongst atoms and molecules at the interface of, say a water and spoon (being used to stir water), authors explains how mechanical work converts into heat.[22] In another example, the presentation of the 'exponential function' in final form (used in classical and quantum

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[21] S. Datta, "Examples to illustrate Newton's third Law of Motion," *Physics Education* 17, no. 2 (2010): 77-86.

[22] D. Jana,"A Critical look to Joule's Law," *Physics Education* 21, no. 1(2004): 61-65.

statistics relating the distribution of energy among particles) creates conceptual hurdles. The related article provides qualitative explanation leading to the mathematical form of the curve. In doing so, address the conceptual gap created by direct introduction probability distribution in mathematical form.[23]

While physics teachers through their publications in the journal have offered the qualitative description of the phenomenon or concepts to compliment mathematical formulation of equations, the issue is brought at the centre stage in PER through concept inventories and various kinds of instructional modules termed as interactive engagements. It is argued in PER that the root of the problem of traditional instruction has been the deficient qualitative experiences provided to the students. The conceptual difficulties encountered by students due to lack of qualitative description in Newton's Laws of Motion and the related concepts are well-documented by Hestenes, Wells and Swackhamer (1992/1995) in the preliminary work on Force Concept Inventory (FCI). The work is also supplemented by Thornton and Sokoloff (1998) in Force and Motion Conceptual Evaluation (FMCE).[24] Thus there is convergence between the publications in *Physics Education* and the instructional modules produced in PER. The difference lies in scientific procedure.

2. It is well established that when elementary and secondary physics instruction does not clarify the ontology of physical quantities, it results in conceptual confusion in students (Chi 1992; Chi, Slotta and deLeeuw 1994; Vosniadou and Ioannides 1998). It appears that physics teachers in their publications also bring forth this issue from introductory and undergraduate physics, for instance, the concept like displacement-current, Maxwell's equations, electromagnetic angular momentum etc. have emphasised this aspect. The description of

[23] D. B. Patil, "Boltzmann distribution law, " *Physics Education* 17, no. 3 (2000): 261-264

[24] 29 multiple-choice questions

physical quantities undergoes a sharp ontological change from particle to field phase when moving from dynamics to electromagnetism. However, there is a correspondence or equivalence of mathematical expressions across (for instance the concept of energy in both of these domains) these ontologically distinct domains. Authors have pointed out the fact that conceptualisation of this correspondence poses a challenge for students and on their part have attempted to provide an explanation to remedy the problem.[25]

3. Historical emanation of relativity in Galileo's principle i. e. acceleration of a body in uniform gravity is independent of its mass and horizontal motion', is brought about in a publication.[26] In one of the publications Maxwell's equations in historical context was discussed in order to clarify the conceptual development of the problem. Another paper covers the thought process behind the formulation of Schrodinger's Wave Equation. It is emphasised that Schrodinger's equation was hypothesised and hence cannot be proved.[27]

   Clearly, like SER or PER, these publications intend to produce historical material for instructional purpose.[28] While, SER is concerned with the production of original material, establishing the validity of the originality of content in aforementioned publications may be contentious.

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[25] For example, I. Eghuanoye, "On the definition of Electromagnetic wave intrinsic impedance,"*Physics Education* 15, no. 3 (1998): 223-227.
B. N. Dwivedi, "On displacement current,"*Physics Education* 9, no. 2 (1992):156-157.
T. Padmanabhan, "Electromagnetic angular momentum," *Physics Education* 23, no. 4 (2007): 285-289.
U. D. Goswami, H. Nandan, C. P. Pandey and N. M. Bezares-Roder, "Maxwell's equations, electromagnetic waves and magnetic charges, "*Physics Education* 25, no. 4 (2008): 251-265.
J. Mitra, "Homopolar generator in rotating referencing frames," *Physics Education* 13, no. 2 (1996): 183-188.
I. Eghuanoye, "Maxwellian force fields in a stationary medium," *Physics Education* 13, no. 4 (1997): 371-375.

[26] A. Bandyopadhyay and A. Kumar, "(2010). Galileo's principle in early models of gravity," *Physics Education* 27, no. 2 (2010): 97-110.

[27] P. V. Panat and A. W. Joshi, "On the feasibility of Schrodinger Equation," *Physics Education* 16, no. 1 (1999):19-22.

[28] Refer to the section on NOS in chapter-II

4. Inadequate and erroneous presentation of concepts in textbooks and by teachers during instruction is another issue brought up in some of the publications. For example, the treatment of the superposition principle, both in classical and quantum physics, albeit with different meanings, is found problematic. Teachers do not clarify the difference in two contexts as well as mention the empirical bases of the respective theory.[29] Does this reflect a lack of conceptual clarity on the part the part of curricular workers and teachers to significant extent? It lacks further work in this direction. Sharma (2007) discusses teacher-trainees' lack of conceptual clarity relating to displacement-current—a concept from introductory physics.[30]It seems to have intimations for the education of both teachers and curricular workers.

When it comes to advanced physics, a significant number of publications relating to quantum physics highlight the difficulties faced by students in grasping the foundational concepts, for example, Dirac delta function, commutation relations, operators, vector space, spin and statistics, wave function, Schrodinger's Equation etc.[31] An attempt to enhance conceptual understanding from an ontological perspectives, is found in 'What is an electron? A particle, a wave or neither', 'When is a wave not a wave', 'Does the electron really spin?', and 'Shapes of Atomic Orbitals'.[32] Visualising the

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[29] A. S. Parasnis, "Principle of Superposition and Superposition of States in Quantum Mechanics, " *Physics Education* 16, no. 1 (1999): 7-12.
[30] K. C. Sharma, "Maxwell's displacement current: Alternative strategy towards functional understanding," *Physics Education* 24, no. 2 (2007): 105-112.
[31] For instance see:
P. R. Subramaniam, B Gnanapragasam and B Janhavi, "Commutation relations as condensed source of information," *Physics Education* 5, no. 2 (1998): 95-96.
V. A. I. Menon and S. K. Menon, "De Broglie phase wave revisited, " *Physics Education* 17, no. 3 (2000): 221-226.
A. Pimpale, "Basic concepts of Quantum Mechanics, "*Physics Education* 19, no. 4 (2003): 319-333.
J. K. Singal, "Why did Dirac need Delta function, "*Physics Education* 27, no. 1 (2010): 5-11.
[32] S. Sanatani, "What is an electron? A particle or wave or neither?, " Physics Education 9, no. 2 (1992): 111-117.
A. W. Joshi, "Shapes of Atomic Orbital, "*Physics Education* 5, no. 1 (1988): 21-24.
A. W. Joshi, "Does the electron really spin?, " *Physics Education* 15, no. 3 (1998):219-221.
A. W. Joshi, "When is a wave not a wave?," Physics Education 15, no. 2 (1998):105-108.

nature of the electron is problematic and the instrumental use of mathematics has to be accepted as the way out according to some papers.[33] Though, PER has captured the difficulties students face in attributing processual or emergent ontology to the physical quantities like force, temperature, heat and current etc., it has not tread into the domain of quantum physics as demonstrated by the physics teachers' in these publications (Docktre and Mestre 2014). In this sense publications in *Physics Education* are a step ahead to PER.

As far as scientific documentation of students' conceptual difficulties and problem solving (appropriately termed as PER) is concerned, besides departments of education and centres for science education, few publications in this domain have come from the department of physics. The studies on pre-scientific or alternative conceptions belong to introductory physics and have explored and tested the concept of force, acceleration, gravity, pressure, heat, temperature, Bernoulli's equation (relating pressure, kinetic and potential energy of fluids) and Maxwell's displacement current. For instance, 'Maxwell's Displacement Current' is easily confused with a peculiar kind of passage of charges from one point to other by school, undergraduate, postgraduate students and physics teacher trainees. Two studies, termed as 'knowledge organisation' are meant to develop the ability to solve problems among undergraduate physics students.

7.4.2 Derivations of Physics Equations (DPE)

The section is devoted to a discussion of the publications that fall under this category and their instructional relevance.

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[33] A similar argument can be observed in the publications from other domains at the post-graduate level. In high-energy physics a large number of publications related to the nature of forces (weak, strong and gravity), nature and composition of sub-atomic particles. Here too, a sizeable number of publications address conceptual difficulties. Papers on laser physics, nano-science, spectrometry and micro-interferometry provide an exposition of concepts as well as instruments and technology. This is true of relativity, astrophysics, solar system, 'allied disciplines' and 'technological areas' as well.

1. Atwood's machine is a mechanical system comprising a set of weights hanging from pulleys. Similar (though not analogous) to the combination of resistors in an electric circuit, the paper on the subject presents the concept of equivalent masses in series and parallel arrangement. The authors have presented a general solution for a large number of related problems.[34] The publication on 'holonomic constraints' in the Langragian Formalism challenges the established thesis that forces of constraints do no work under virtual displacement. The author proposes a general equation, of which the 'no work assumption' comes out as one of its solutions.[35] In another publication, the relation between the velocity of a liquid (v) through a pipe (during streamline flow) and its radius (z) in the region sufficiently close to the orifice is established. As velocity was found to be a quadratic function of the radius, the outcomes of the formulations deviate from the 'streamline region'.[36] The general formula for the modes of oscillation of a 'massive' spring (meaning that mass of spring has to be taken into account) is derived. The formulation reduces to the standard one (for light spring) presented in the textbooks.[37] Similarly, a general equation for the exchange of angular momentum of the electromagnetic field with the system of charged particles is formulated. The equation is found to yield unexpected results.[38] In a problem from the field of optics, the authors discuss the parameters responsible for the conjugate relation between the optical paths joining the two points. The expression reduces to the well-known Lens-Makers formula for a thin

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[34] M. J. Mehndi and B. A. Ahmad, "Investigation of Atwood's Machines as Series and Parallel Network," *Physics Education* 27, no. 4 (2010): 239-247.
[35] B. Chakraborty, "Holonomic constraints in Classical Mechanics, "*Physics Education* 14, no. 2 (1997): 169-174.
[36] E. O. Ekpe, "Efflux velocity and small pressure-heads," *Physics Education* 10, no. 2 (1993):176-178.
[37] H. C. Pradhan and B. N. Meera, "Oscillations of a spring with non-negligible mass," *Physics Education* 13, no. 2 (1996):189-193.
[38] T. Padmanabhhan, "Electromagnetic angular momentum, "*Physics Education* 23, no. 4 (2007): 285-289.

lens and has useful implications, for example, helping locate the principal planes of a thick lens.

2. In another publication the authors show the relationship between seemingly disparate phenomenon. The motion of a particle or ball on an inclined plane is progressively related to Rutherford's experiment on the scattering of positive ions by the nucleus of the atom. The relation is further extrapolated to the mechanism of Higgs particle.[39]
3. In yet another publication, a close analogy is established between the modes of the compound string and Kronig-Penney model in solid state physics.[40] As claimed, pedagogically useful similarities and differences between the two systems are pointed out.[41] The generalisation or analogical extension of quantum concepts to classical physics (by way of the 'correspondence principle') is reflected in some of the publications. For instance, the expression for the resonance frequency $(v = \frac{1}{\sqrt{LC}})$ for an alternating current flowing through a LC-Circuit is derived from Langrangian (classical) as well as quantum mechanical theory.[42] The results are found to be exactly similar. The inference is drawn that the energy levels of the quantum LC-circuits are quantised like the 'Harmonic oscillator'.
4. Taking up a concept presented in textbooks, a publication provides a comparative analysis of how heat lost in cooling is not the radiation loss as erroneously mentioned in Indian textbooks (i. e. Newton's law of cooling is completely different from Stefan's law of radiation).[43] Similarly a correction is offered for the misconception relating the formation of multiple images by a point object placed between two inclined mirrors.

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[39] O. P. Dam and T. Wibig, " Inclined plane view from above; and what Higg's has to do with it?," *Physics Education* 27, no. 4 (2010):257-266.

[40] The Kronig-Penney model is a simplified model for an electron in a one-dimensional periodic potential.

[41] S. Bharve and S. C. Pradhan, "Modes of a "Kronig-Penny" String, "*Physics Education* 9, no. 1 (1992): 32-39.

[42] The symbols ϑ, L and C stand for frequency, inductance and capacitance, respectively.

[43] D. A. Desai, "Newton's law of Cooling, "*Physics Education* 23, no. 1 (2006): 51-54.

While paper devoted to the 'exposition of content' aim to enrich the conceptual, historical and applied aspects of content, publications under this head involves the resolution of the conceptual and theoretical problems confronted during the course of teaching and learning process. Logical organisation of axioms and the mathematical formalism dominate the content of the publications under this head. It does not differ from the curriculum in as far as they subscribe to the axiomatic construction of theory and derivation of mathematical equations (also pointed out in the previous section). Thus, pedagogically, readers (students and teachers) are expected to be well-versed with the structure and underlying meaning of the content (concepts and theory). Having read the publications readers can enhance their problem-solving repertoire, update instruction practice or get equipped to appreciate similar problems and take up them to resolution themselves.

On the other hand, the developments in PER suggest that quite often exclusive emphasis on the formalistic presentation of the content to a large extent is the cause of students' learning difficulties. Presentation of mathematical equations and formalism of physics in traditional instruction does not adequately explain epistemological and ontological facets of physics and thus poses conceptual difficulties for a majority of the students. The tendency of rote learning or blindly reproducing algorithms and applying mathematical equations in problem solving is a reflection of this problem (Hestenses, 1987, 2006, Halloun, 2007; Kurki-Suonio, 2010). Abysmal debates and work on the explication of the logico-mathematical component of physics for instructional purpose was mooted by Joshi and Tillu (1989).[44] Only two articles reflecting the nature of mathematical formalism have made a bid to address the issue. Eghuanoye (1998), in his article titled "On the teaching of

[44] In the article titled, "Importance of a quantitative approach in understanding concepts in physics" Joshi and Tillu (1989), while appraising the work accomplished on experiments, they caution against the overarching significance attached to the experimental component while underplaying or altogether ignoring the logico-mathematical structure of physics theory. In their view, commensurate emphasis needs to be placed on the latter..

physics" points out the difficulties students confront in making sense of the mathematical language used for dealing with concepts. According to him, in contrast to the world of visual forms and patterns, mathematical expressions in physics are non-pictorial or formless in appearance. This poses difficulties for students in grasping the conceptual structure underlying mathematical expressions. On his part, author has offered a reconstruction of mathematical formalism. In another article entitled "On the learning of physics" he has further elaborated upon the issue.[45]

Is this sufficient an attempt to resolve the issue or it needs to be further problematised and resolved? For instance, as shown earlier, analogous relations (analogy) are ubiquitous in physics and facilitate the process of conceptualisation. However this in itself does not happen to be sufficient for the conceptualisation of the underlying concept. Intermediate analogy between anchoring and target analogy, called 'bridging analogy' becomes inevitable for facilitating the learning of analogical reasoning (Clement, Brown, and Zeitsman (1989). Here compound pendulum being the anchoring analogy and Kronig-Penney model the target analogy.

7.4.3 Problem Solving

The publication of articles under the rubric of 'Problem solving' has been a feature of the journal since its inception. The readers are asked to pose as well as offer solutions to problems relevant to introductory, undergraduate and postgraduate physics.[46] However, after making a beginning, the publications in this domain have gone through phases of passivity and subsequent revival. A separate section on posing exemplary problems and their resolution was restarted from the year 2005 (Mani 2005).[47] The activity is sustained on continuous based since then.

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[45] I. Eghuanoye, "On the Learning of Physics, "*Physics Education* 15, no. 2 (1998):131-136. I. Eghuanoye," On the Teaching of Physics, "*Physics Education* 14, no. 4 (1998*):* 303-308.
[46] O. N. Awasti, "(2001). Development of problem solving skills in physics and quality teaching," *Physics Education* 17, no. 4 (2001): 351-354.
[47] H. S. Mani, "Physics through problem solving-1: Problem in Relativity," Physics

The problems discussed in this section are not different from the ones presented in the textbooks. Indeed they are useful for readers (teachers and students) proficient in problem-solving. On the other hand, in the light on the work done on 'problem solving' in PER, from instructional point of view, this is problematic in nature (Gerace and Beatty, 2005). As with conceptual problems, the problems are formulated keeping in mind the axiomatic deductive form of physics instruction. As such, the approach ignores the tacit conceptual and procedural knowledge and does not reveal their importance (Reif and Heller 1982; Hestenes 1987; Halloun 2007). It is precisely because of this reason that there is a marked difference in the problem-solving ability of experts (or teachers) and novices (or students) (Gerace and Beatty, 2005). Ironically, despite the ample evidence, there is no methodological initiative investigating and offering solutions to students' difficulties in 'problem solving' in physics. It remains reproduction of traditional instruction.

7.4.4 Manual and Computer-interfaced Experiments

Let us now consider some representative examples on the nature and purpose of these publications. To begin with take an experiment developed at Indian Institute for Science Education and Research (IISER) Mohali. The experiment estimates the drag force acting on a magnet falling through a thick conducting cylinder. The experimentally estimated drag force agrees fairly well with the theoretically predicted value. The experiment is recommended for the undergraduate course.[48] Another experiment was conducted at the National Physics Olympiad cum Selection Camp held at Home Bhabha Centre for Science Education (HBCSE) in May 2009. The experiment estimates the infinitesimal change in the width of the diffraction slit while being heated. The change in width is measured by recording the corresponding change in

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Education 22, no. 2 (2005): 153-156. H. S. Mani, P. K. Panigrahi, and T. R. Seshadri were asked to coordinate this section.

[48] A. K. Arora and S. R. Sharma, "(2003). Fall of a magnet through a thick conducting cylinder, " *Physics Education* 19, no. 3 (2003): 307-312.

the diffraction pattern.[49] Clearly, the experiment is a slight modification over its textbook version. In the same category other experiments include the measurement of Sun's diameter during the total solar eclipse and the design of telescopes.[50]

In yet another experiment, an anharmonic oscillator was prepared by adding a permanent magnet with the geometry of a compound pendulum. This was a geometrical modification of compound pendulum and makes the restoring force a function of displacement, potential energy and time period in a single arrangement.[51] Similarly, dependence of the time period on a number of parameters is reported in the experiment on the sectioned-cylindrical pendulum. In addition to acceleration due to gravity, the time period of such a pendulum is found to depend on the radius of centre of gravity, radius of gyration, radius of curvature (locus of centre of mass during oscillatory motion) and the geometrical radius of the cylinder.[52]

It is around three decades now that computer-interfacing of manual experiments for instruction was introduced (Wilson and Redish 1989). Physics teachers in India, since as early as mid 1990s, have also reported the work in this regard. The study of diffraction through single and multiple slits with the interfacing of a computer and Helium-Neon laser is one of such example. The variation in intensity distribution of the diffraction pattern of a single slit width and those of multiple slits is graphically analysed on a computer and is

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[49] S. R. Pathare, R. D. Lahane and M. K. Upadhyay, "Coefficient of linear thermal expansion," *Physics Education* 26, no. 2 (2009):135-150.

[50] N C Rana, "A brief report of preliminary results of IUCAA's eclipse expedition, " *Physics Education* 13, no. 1 (1996):93-98.

N. C. Rana, "A project on measurement of Sun's diameter during the total solar eclipse of October 24, 1995,"Phy*sics Education* 12, no. 2 (1995): 178-182.

Ved Ratna, "On better conduct of telescope-making workshops for school students,"*Physics Education* 12, no. 4 (1996): 354-357.

[51] Y. K. Vijay, "Laboratory experiment on anharmonic oscillator," *Physics Education* 10, no. 1 (1993):116-122.

[52] C. B. Joshi, "Oscillatory Behaviour of a Sectioned Cylinder," *Physics Education* 13, no. 1 (1996): 69-73.

experimentally demonstrated by using laser light. The width of a single slit was determined from the study of the diffraction pattern.[53]

It is apparent that attention to conceptualization and design of experiments by even a small section of teachers and students can trigger a great deal of interest. The nature of experiments ranges from modification of the existing curriculum to the novel construction. As such they are not only the contenders for inclusion in the curriculum but also can potentially motivate the readers (fellow teachers and students) to enrich or as contended by Saraf (in Saraf et al. 1979) and Khandelwal (1984, 1993), even redefine the purpose and nature of experimental work in introductory and undergraduate physics.

7.4.5 Exemplars of Teaching through Expositions and Experiments

As pointed out in table 7.1 and 7.3, respectively 0.69% of the publications belong to exemplar teaching by exposition and 0.97% by experiments and demonstration, respectively. Following are the exemplars discussed.

Starting with occasional reports on exemplar teaching acts, the idea was deliberated upon regularly by the editors. For example, H. I. Zhang (1992), adding to the description cum formula based mode of teaching traditionally in practice, reported on the geometrical exposition of the Lorentz Transformation in the domain of special theory of relativity. Similarly, during 1997, under the head of 'Teaching modern ways', A. S. Prasinis offers comments on the teaching of various concepts (photon-waves complementarity, superposition principle, coherence etc) in the domain of optics. Likewise, V. G. Jadhao (2000) throws light on the history of concepts such as temperature, internal energy and entropy. With this initial push, the activity was supposed to acquire momentum. To the dismay of editors, there was little response from physics teachers on a sustained basis and eventually a few publications appeared. What does this reflect? Is it that these teaching

[53] T. Kurivilla, V. K. Vaidyan and K. Shantinanthan, "Diffraction through single and multiple slits--a comparison of simulated and experimental results," *Physics Education* 8, no. 4 (1992): 355-358.

acts did not offer novel perspectives to the readers? Or was there, as suggested by David Hestenes (1987, 1), a general lack of interest from physics teachers in pedagogical work?

Now turn to the acts of teaching through experiments. Over the years, the idea of 'concept experiment' or 'concept centered experiment' as the basis for concept development has been debated among IAPT members (Khandelwal 1987, 109-113; Joshi 1999; Datta 2001).[54] To give practical shape to the idea, publication under the rubric of 'physics through teaching laboratory' (PTL) and 'teaching concepts through laboratory' (TCL) were initiated by the journal. A call was issued to teachers and researchers to come up with a reasonable response to this pedagogic initiative.[55] Three publications exemplifying the idea are discussed below.

The idea under PTL is exemplified by the experiment on simple harmonic motion. Prescriptions are provided to space out the observations and keep oscillations within the linear zone (in the region of small displacements).[56] For instance, it is suggested that the pendulum should be released gently from the displaced angular positions to prevent additional reactions at the axis of rotation to sustain harmonic oscillations. The title, "How simple is simple pendulum" exemplifies the conceptual counterpart of the above experiment. Making a departure from convention, the progression from the linear to anharmonic region (the region of larger displacements) is expounded in a single experiment. Solutions for the anharmonic region are obtained as the

[54] Joshi (1999) contends that experiments in the physics curriculum are merely result-oriented. Having inhibited exploration of physical phenomenon, it limits the scope of concept formation. Quite often pursuing experimental activity in this format becomes pedagogically limited. The paper, "Overhauling the undergraduate physics laboratory in India" reports the outlines of the 30 'concept experiments' aims to visualize a model undergraduate physics laboratory.

[55] H. C. Verma, S. K. Dutta and D. A. Desai co-ordinated the section.

[56] N. R. Bhamare and D P Khandelwal,"On the planning of a teaching laboratory-experiment 1: variation in the period of simple pendulum with amplitude," *Physics Education* 12, no. 2 (1995): 174-177.

general case and simple harmonic motion is a particular approximation.[57] Similarly, the concept underlying the rolling motion of a dumbbell shaped body on a plane is highlighted. The plane formed by two parallel metallic rails, is designed to illustrate role of static and rolling friction.[58] The paper on "Procedural understanding: a neglected aspect of physics laboratory training" though does not fall within in the PTL theme, it discusses the nature of procedural understanding required in designing, measurement, data handling and evaluation of an experiment.[59]

Traditionally the experimental activity overemphasizes the measurement of the final value needed to verify theory (Trumper 2003; Koponen and Mantyla 2006). As such it does not have the scope for generating perceptual and empirical meanings and the transformation into concepts, models, mathematical equations, theory building and back to experimental validation of the new models generated from theory. It is contended that to a large extent, the difficulties of students with physics emanate from the inability to establish linkages between the experimental, conceptual and theoretical parts of physics (Hestenes 1987, Koponen et al. 2003; Kurki-Suonio 2010). The idea of promoting learning of concepts under PTL appears to be a step to accomplish this objective.

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[57] P. Arun and N. Gaur,"How simple is simple pendulum, "*Physics Education* 19, no. 3 (2002): 185-1991.

[58] D. A. Desai and S. R. Pathare, "Rolling Motion," *Physics Education* 23, no. 2 (2006): 127-134.

N. R. Bhamare and D. P. Khandelwal, "On the planning of a teaching laboratory: Experiment 3-Oscillations under gravitational plus magnetic potential fields," *Physics Education* 13, no. 1 (1996): 79-85.

S. A. Agte and D. P. Khandelwal, "On the planning of a teaching laboratory experiment 2: Study of a coupled oscillator comprising two simple pendulums," *Physics Education* 12, no. 3 (1995): 269.

[59] R. B. Khaparde and H. C. Pradhan, "Procedural understanding: a neglected aspect of physics laboratory training," *Physics Education* 19, no. 2 (2002): 147-154.

R. M. Dharkar, "Classroom demonstration: An Introspection, "*Physics Education* 18, no. 2 (2001): 157-158.

7.4.6 Philosophy of Time and Reflections on the Relation between Physics and Life

Two types of literature have been published on 'philosophical reflections'. The first deals with reflections on the nature and impact of physics. The reflections cover the relationship of physics to human perception, society and life as a whole. For example, the publication entitled "Messages from physics: similarities between physics and Human life" argues that the ideas emanating from physics have a multifaceted influence on the social, personal, environmental and economic aspects of life.[60] Though, the nature of these publications reflects a tendency to take physics beyond the instructional context, as far as philosophical rigor is concerned, they appear to be naïve descriptions.[61] In its current form, the literature does not seem to have any direct implications for instruction, though it does carry intimations of a desire to conduct or appreciate philosophical analysis in their discipline.

Secondly, a series of expositions have been brought about on the nature and associated paradoxes relating to the various facets of 'time' (10 in number or 1.37%)—i. e. philosophy, Newtonian mechanics, relativity, thermodynamics, and cosmology etc. Interestingly, time is the only concept undertaken in these analyses and virtually (except one) all of the publications have come from a single author.[62] The publications may serve as supplementary texts for the

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[60] K. Jain, "Messages from physics," *Physics Education* 18, no. 3-4 (2001-02): 203-207.
See also: S. N. Tripathi, "Age and achievement in science: Some interpretations," *Physics Education* 6, no. 3 (1991): 264-266.
N. C. Varshneya, "Nature, Technology and Society--an Indian View," *Physics Education* 7, no. 1 (1990): 35-42.

[61] Other publications approach this problem from philosophy and developmental psychology. For example the weak and strong version of 'Anthropic Principle' expounds man's place in the overall scheme of things in the universe. Obviously these publications are exclusively confined to their respective disciplinary boundaries. Thus the titles such as, "Concept of Matter and Causality in Indian Thought" and "Cognition: a unique capability of Human life" may only be indirectly relevant to the physics instruction.

[62] The expositions aim to cover large gamut of work on the subject. For instance in the paper, titled-"On time- I: Philosophical time.", author elaborates upon the emergence and successive attempts to resolve the paradoxes of the vanishing present, the paradox of unreal time, McTaggart's paradox, Dumett's paradox, Aristotle's sea battle, the master argument of Diodorus Cronus, Zeno's paradoxes of motion, and the Thomson lamp. Likewise every article related to this category deals with the paradoxes and their possible resolutions with its ramifications.

interested teachers and students.

Summary and Conclusion

Bibliometric analysis of the journal of *Physics Education* reflects the nature of work the Indian physics education community has engaged with. Expositional literature takes up the elaboration and illustration of conceptual, logico-mathematical (axiomatic), historical and applied facets of the content. It occupies the major share (35.72%) of the overall publications. Objective of these publications is to enhance the knowledge horizon of the readers as well as add to the quality and quantity of the textbook content. As a segment of this literature engages with the identification and resolution of conceptual difficulties faced by the students, it resembles 'alternative conceptions' in PER. Though lacking in explicit theorisation, treatment of ontological, epistemological, analogical and metaphorical dimensions of physics content resembles the idea of 'conceptual-ecology' due to Posner et al (1982). In fact the journal appears to bring them forth in clearer terms than revealed in IAPT's work. Presence of large quantity of these publications from quantum mechanics and other domains of higher physics appears to surpass similar literature from PER. In few cases, this is supplemented by the 'teaching acts' demonstrating the resolution of conceptual difficulties.

Alternative reformulation of equations, problem-solving and inter-domain theoretical synthesis across classical mechanics, relativity and quantum physics comprises of 6.89% of the publications. Investigative studies cover topics from introductory to research levels and shares 11.44% of the overall publications. The reviews of research studies, laboratory techniques, research facilities and scientific instruments aim to facilitate the absorption and consolidation of the newly emerging content in the curricula and instruction.

See: C. K. Raju, "On Time-I: Philosophical Time, "*Physics Education* 7, no. 3 (1990): 204-217 and other articles in the journal.

Investigative studies, exposition and reviews are also extended to the allied disciplines of physics and technological fields. Mostly, publications falling under allied disciplines bring in inter-disciplinary content from chemistry, material science, atmospheric sciences etc. They share 06.20% of the publications. Publications under technological fields constitute 3.58% of the publications and cover a wide spectrum of sub-domains like information technology, metallurgy, energy, remote sensing, radiology, electronics etc.

Design and improvisation of manual experiments has 13.65% of the share in the overall publications and like IAPT, reflects significant engagement from the larger physics education fraternity. The literature reveals that experiments are both a modification of the ones existing in the curriculum as well as incorporate novel features. 07.31% share of publications belongs to the application of computers in interfacing experiments and content representation. Computer applications in physics instruction via interfacing of manual experiments, simulations, graphics and mathematical derivations are aimed to add the manual experiments and blackboard representation of the content. Like IAPT, 'physics through teaching laboratory' (PTL) and 'teaching concepts through laboratory' (TCL) were initiated by the journal to encourage readers (teachers) make concept 'centred-experiments' integral part of their teaching.

In line with the objectives of the journal (listed in the footnote no. 18 in this chapter), occasionally articles reflecting the relationship between physics, life and society have appeared in the journal. Though giving space to philosophical reflections from physics teachers and researchers, they are far from disciplinary rigour. Similarly articles throwing light upon the nature and structure of mathematsation in physics have found place in the journal.

Since over four decades science and physics educators have produced substantial literature. However, the insights from this research have still to percolate down to the field. A small fraction (3.72%) of the publications belongs to PER and has come either from the departments of education or Homi Bhabha Centre for Science Education (HBCSE). Whereas PER is characterised by concerns with the theoretical framework, scientific evidence and validation of the pedagogic data, the literature produced by faculty from the department of physics belonging to college and universities is based more on teachers’ experiences and perceptions.

Teachers at the highest strata of education not only provided editorial and other services required to run the journal but also share more than 65% of the publications. Publications from college teachers comprised just 12% of the overall authorship. School teachers have not contributed to the journal. Disproportionally high quantum of publications from Pune University (26%) or the universities from the state of Maharashtra (38%) is another surprising trend reflected.

Chapter 8

Summary and Conclusion

IAPT: Formation, Policies and Programmes

The formation of the Education Commission (1964-66) was a landmark in creating a new vision of education in India during the 1960s.[1] The commission encompassed all the domains of education from elementary to tertiary level. Following the commission, the Srinagar deliberations in June, 1970 brought out a viable plan of action for the implementation of its recommendations in tertiary physics education. A shift was made from the teaching of facts to the clarification of concepts, deduction of laws and equations, solving of problems in diverse physical contexts and employing experiments not only for verification but also investigating and deducing concepts and laws. The establishment of science teaching centres was recommended as a site for pedagogical reconstruction (UGC and UNESCO 1970). This was an advance over the existing practice though physics teaching-learning remained within didactic fold.

Following the framework sketched by the Srinagar deliberation, the University Leadership Programme (ULP) and College Science Improvement Programmes (COSIP) were launched by the UGC. The projects ran throughout the decade of the 1970s and undertook the development of textual material, experiments and related methodology (UGC 1982). Establishment of Indian Physics Association (IAP) (in 1970) and launching the journal of *Physics Education* (in 1973) were the other important initiatives undertaken following the recommendations of the Srinagar deliberation.

The Universities of Bangalore, Madurai, Mysore, Andhra, Nagpur, Bombay, Poona, Rajasthan, Punjab and Ranchi were assigned ULP and COSIP projects (UGC, 1982). Though, textbooks, experiments and other curricular material were produced by most of these centres, it hardly finds mention as an

[1] Refer to the report of the Education Commission (1966).

alternative or advancement over the existing material. As an exception, notable work was undertaken under the leadership of Babulal Saraf at ULP Rajasthan (University of Rajasthan) where highly innovative experiments were developed in different domains of physics. The experiments were brought out in book form in two volumes entitled *Physics through Experiments*.[2] The replicas of these experiments were sold across various colleges and university departments of the country (Kumar and Nigavekar 1994). As a result ULP and COSIP groups working in other parts of the country gravitated towards this centre. Subsequently, ULP centre at this place became a site for interaction among the physics education fraternity across the country (Lokanathan and Sharma 1984; Kumar and Nigavekar 1994). In 1978, this ULP centre was upgraded as the Centre for the Development of Physics Education (CDPE) (Vigyan Prashar 2009). A conference held at the Department of Physics Rajasthan University from Dec 29, 1983 to Jan 2, 1984 concluded a decade long engagement in ULP and COSIP projects (See Loknathan and Sharma 1984).

The gathering of ULP and COSIP groups at the conference opened the way for the formation of the Indian Association of Physics Teachers (IAPT). Eventually, a group of physics teachers and researchers under the leadership of D. P. Khandelwal initiated efforts to establish the association in February, 1984 at Kanpur (IAPT 1984, 2-3). Starting at the regional level the association acquired an all India stature at its first annual national convention at Kanpur held between 21 to 23rd October 1984 (Khandelwal 1984, 24).

Tapping the potentialities of Indian physics teachers in resolving the problems of undergraduate physics education in India became the aim of the association (IAPT 1984, 4). Being foundational, school physics became an

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[2] Babu Lal Saraf et al., *Physics through Experiments-1: EMF Constant and Varying,* 2nd Ed. (New Delhi: Vikas Publishing House PVT LTD, 1978).
Babu Lal Saraf et al., *Physics through Experiments-2: Mechanical Systems-Study of some Fundamental Processes in Physics* (New Delhi: Vikas Publishing House PVT LTD, 1979).

integral part of the association's engagement. The impact of the policy framework formulated during the Srinagar Conference together with the ULP and COSIP experiences is evident in the major objectives of the association. The task demanded intense debates and rigorous analysis of the existing curricula in the country. With the ULP and COSIP projects in the background, IAPT looked at PSSC and Berkley Physics as a model worthy of emulation (Khandelwal 1986, 30, 302; Biyani and Tutakne 1989, 194-196). In need of sufficient financial outlays, the association desired government agencies like UGC or NCERT to support its endeavour or go solo to evolve pathways to achieve its aim independently (Khandelwal 1985, 3-6).

Production of Textual Material: An Unrealised Aspiration

Proposals for writing a book on electricity and magnetism for B.Sc. and a textbook for class 11 were submitted (IAPT 1986, 84-86). Unlike ULP and COSIP projects, funds were needed to carry out the work. Being at the early years of its existence, the IAPT did not find itself composed enough to take strides in this direction. The failure of the programme of textbook writing at the outset was a setback for the morale of the association.

Apparently, producing relevant textual material demands a fair degree of research on the subject. Articulation, explication and representation of tacit knowledge of the practitioners demand active and sustained engagement. This in turn demands new ways of conceiving and investigating the problem (Schon 1995, 2001). The developments in the field of physics education research (PER) over several decades substantiate this contention. Researchers (physics teachers) incorporated ideas from cognitive psychology and philosophy of science to interrogate the existing practice. Over the course of time there arose a community of scholars on the subject where research outcomes were discussed and peer reviewed (Duschl 2008). A prolonged engagement of its members with physics pedagogy resulted in the publication of textual material (See the Resource letters brought out by McDermott and Redish 1999; Meltzer and Thornton 2012).

Similar patterns can be found in the case of IAPT. The long term engagement from a few of its members happened to result in the production of textual material. Three manuscripts were produced by Ved Ratna and K. C. Thakur on cost-effective optics experiments for secondary, senior secondary and undergraduate levels respectively. Having incorporated the PER perspective, a textbook for the XIth standard by Rakesh Popli was published posthumously.[3] Publication of a series of *Horizon of Physics* by IAPT is another notable accomplishment..[4] The collaborative effort in bringing up this work resulted in a feeling of collegiality among IAPT fraternity.

NSEP and NGPE: Reproduction of a Tradition

The development of a voluntary standard examination for undergraduate students at the national level was one of the key recommendations of the Srinagar deliberation. Apparently, no conclusive work was undertaken in this direction during the ULP and COSIP projects. The creation of the National Standard Examination in Physics (NSEP) and National Graduate Physics Examination (NGPE) in 1987 and 1988, respectively, by IAPT was to accomplish the unfinished task. Undertaking this task was the second major initiative undertaken by IAPT (IAPT 1992, 255). The intent was to make a shift from the excesses of facts and verificatory experiments to the testing of conceptual understanding, problem solving and concept-centred experiments in physics examination. Implicitly, the examinations were supposed to trigger the renewal of pedagogy and textbook writing (Anand 1988, 74). As a potential catalyst for making change, in the initial years the examination was seen as a landmark event in the growth of IAPT (Maity 1989). The huge voluntary effort required to hold these examinations brought the IAPT members together as a cohesive unit and spread its membership throughout

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[3] The manuscripts are unpublished. Refer to the Ved Ratna (1993) and Ved Ratna and Thakur (2003, 2006). The book written by Rakesh Popli is entitled, *Physics Textbook for Class XI* [Refer to: R. K. Popli, "Obituary," *Bulletin of IAPT,* Nov, (2007): 344.]

[4] Refer to: the *Horizon of Physics* series by Joshi and Hans (1989), Nath and Joshi (1996) and Gupta (2002), respectively. It is recalled that the series of *Horizon of Physics* comprises of a collection of review articles meant to serve as a supplementary reader for the teachers, advanced students at the undergraduate level and as M.Phil coursework material.

the country.[5] For three decades these examinations continue to be the core of the programme and are widely acknowledged activity pursued by the association.

Unlike scientifically validated assessment tools such as Force Concept Inventory (FCI) or many other concept inventories (CI) developed by physics teachers involved in PER, NSEP and NGPE are validated by experts' subjective judgements and from the disciplinary perspective hardly any novel dimension appear to be added to it.[6] While Concept Inventories (CI) are meant to diagnose students' conceptual difficulties, NSEP and NGPE are used to test achievement and aptitude. NSEP scores are used to provide national ranking and the top scorers are selected for the preparatory training programme for the participation in the International Physics Olympiad. NGPE is also considered more standardised or representative than its counterparts in postgraduate entrance examinations conducted by various universities and national institutions in India.[7] The results of CIs are useful in providing systematic data on the students' ability to discriminate between what is generally termed as pre-instructional conceptions and scientifically correct responses. Keeping this data in the foreground, physics teachers could devise alternative instructional modules to help students shed their pre-scientific conceptions and assimilate the scientifically correct ones (Hake 2011).[8] The case with NSEP and NGPE is different. In the initial years there were talks about the analysis of the answer sheets of the examinees; however no work was conducted in this direction (IAPT 1987, 175-183; Anand 1988,

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[5] As per the constitutional (refer to the appendix-4.1) directives of IAPT, no remuneration will be paid to members for conducting work of the association.

[6] Question for the examinations are collected by holding a competition among the members. The best questions or question papers in the examination are further scrutinized by experts before they are included in the examination.

[7] The statement was given by the participant students (Nadiabihari Pradhan from Orissa, for instance) C. K. Majumdar Memmorial Summer Workshop in Physics (organised by IAPT and S. N. Bose National Centre for Basic Sciences (SNBNCBS), 01-12 July, 2013 at SNBNCBS, Kolkata). By that time these students have already gone through the postgraduate entrance examinations conducted by various universities and National Institutions.

[8] PER instructional module are based on prior research into students' conceptions, for example *Peer Instruction* by Mazur (1997) was based on the results of FCI.

74). This put a full stop in adopting or devising novel perspectives for further standardisation or effective calibration of NSEP and NGPE.

The theoretical component i. e. testing of facts and concepts (termed as part A and testing of concepts and problem solving termed as Part-B) of the NSEP and NGPE is projected as the model examination worth imitation by schools and colleges. The testing of conceptual and procedural knowledge involved in experiments (termed as Part-C) was included from 1992 and 1993, respectively. Similarly adding this component to the examination was seen as a new beginning (Srinivasan 1992, 156; Khandelwal 1993, 178). Developing and executing the experimental component of NSEP (Part-C) in 1992 and 1993 with NCERT was the high tide of IAPT's collaboration with national bodies. For a short period of time though, it raised hopes among IAPT members for opening up a debate on the reconstruction of the experimental work in school physics. The programme was conducted with tremendous enthusiasm and attempts were directed towards some sort of standardisation of the questions.[9] As it happened NCERT opted out of the joint venture in 1994. IAPT had to move on at its own thereafter.

The idea of developing NSEP for India's participation in the International Physics Olympiad was given a thought and supposed to be another step to scale up the examination in 1995 (Srinivasan 1995; Prakash and Ratna 1995). Also unsuccessful efforts to raise funds for IAPT's academic complex were initiated in the same year. The death of D. P. Khandelwal in the February 1996 was major setback for the association (Samanta 2001). As a result IAPT could not initiate India's participation in the International Physics Olympiad. Having established credentials as a premier science education research institute, HBCSE was considered the appropriate venue for organising the preparatory programmes for India's participation in the International Physics Olympiad in 1998 (Kumar 1998, 220-221). The credible expertise of IAPT in

[9] Refer to appendix 3: NSEP Part-C 1993 and 1995 examinations.

organising NSEP and NGPE, disposed it to take part in this examination. As a matter of fact, working with HBCSE in organising the preliminary phase of the Indian National Physics Olympiad (INPOpiad) 1998 was the second collaborative programme undertaken by IAPT. IAPT's experience and expertise in organizing the NSEP became the preliminary stage in the selection of meritorious students for not only the Indian National Physics Olympiad (INPOpiad) but also its counterparts in chemistry and biology (Chattopadhyaya 1997, 341). Apparently, ample material support came from the government for holding the examination. Unlike NSEP and NGEP, INPOpiad is not limited to the examination. Its activities not only include a training programme focused for sorting out conceptual and experimental difficulties of participating students but also enhancing their knowledge and skill repertoire. HBCSE has the responsibility of reconstructing the theoretical and experimental component of the INPOpiad (Desai 2004, 305-306)

Though a sound beginning was made in conducting the experimental parts of NSEP and NGPE, a break took place between 1996 and 2001. Samanta (2001) appears to suggest that this had to do with a lull in the activities of the association. Khandelwal was perceived as the force behind the formulation and execution of the programmes of the association. With his demise, the inspiration to take the examination forward was lacking. R. N. Kapoor believed that the organisation of experimental examination for INPOpiad by HBCSE (from 1998) drew on the energies of the active IAPT members. Testing experimental knowledge and skills was part of the INPOpiad, so IAPT members became reluctant to duplicate their efforts. When the examination was revamped in 2001, they were not enthusiastic enough to benchmark the examination at the national level. Consequently, the examination has become an annual ritual, leaving the ideal of standard examination in experimental activity aside.[10]

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[10] Interview with R. N. Kapoor at Anveshika, Dec 4, 2012 (30 Nov-11th December, 2012 visit).

On the financial side NSEP and NGEP generated appreciable revenue out weighing all other grants coming from different sources. Given the large number of students appearing for these examinations coupled with the voluntary service provided by the huge army of IAPT members, the corpus of the association was built up.[11] This was enough to sustain the activities of the association.[12] The funds generated from the examination play a decisive role in gaining financial autonomy needed for the survival and progress of the association.[13] With the spread of the examination, the membership of the association is continuously increasing.

The Centre for Scientific Culture (CSC)

The revision of experiments has been the major way to renew the pedagogy of physics in India (Saraf in the preface of Saraf et al. 1979; Khandelwal 1984, 83-90). The Centre for Scientific Culture (CSC) gave practical shape to the IAPT's stated objective in this regard. The CSC was supposed to be a repository of working experiments for school and college students as well as the general public. Twelve institutions competed for establishing 4 model CSCs to be developed in different parts of the country. Only two qualified (Khandelwal 1993, 284). Lacking in the commitment and application, the CSC at Nagpur also ceased to be active after a few years of its establishment. The CSC at Midnapore continues to find mention among IAPTs activities till today.[14]

According to Samanta, significant effort has been invested in developing and sustaining the CSC Midnapore for several years now. Curricular activity in 'project work' undertaken by the undergraduate students was made the core activity of CSC (Samanta in 2011 [interview], 2013 [presentation] at

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[11] "Minutes of the Executive Council Meeting of IAPT," *Bulletin IAPT* 5, no. 5 (1988): 170—173.
"NGPE 23rd 2011," *Bulletin of IAPT*, Sept (2010): 287

[12] "Account for the period Jan, 1988 to Nov 20, 1988," *Bulletin of IAPT* 5, no. 12 (1988): 349.
"Income and Expenditure Account for the Year ended 31 March 2008," *Bulletin of IAPT*, Oct (2010): 317.

[13] Anant Krishanan at IAPT's Annual National Convention at Chandigarh in 2014

[14] Having spent Rs. 5.2 lakhs on two CSCs, the remaining money (Rs. 5.59 lakhs) was returned to MHRD. Source: Khandelwal (1991, 160) and Khandelwal (1993, 283-284).

Midnapore and Kolkata, respectively). This involved cooperation between Samanta and his students and fellow teachers. As a result the centre figures as a key site in IAPT's portals and manifestos. The lack of data or absence of formal documentation of CSC's work in the past decades makes it difficult to say anything more.

While the thrust of experiments for so many years was on exposition of concepts, now there is shift towards 'problem solving' (Samanta 2013, Kolkata [presentation]). Problem-solving exercises are tied to experimental activity. For instance, problems about the simple-pendulum can be connected to a great deal of experimental activity. Similarly, two pendulums of nearly (not exactly) equal lengths can be arranged side by side and the phenomenon of dissonance and consonance can be demonstrated experimentally and linked with its problem-solving counterparts.[15] Pedagogically, if the 'problem solving' is theoretical in nature (as it is generally understaood), the direct linkage of experiments with it proves to be a distraction (Kreitler and Kreitler 1974). However, 'problem solving' act connotes to the execution of experimental activity by applying the required conceptual and procedural understanding. In the Indian context, founded on a well articulated theoretical framework, the approach has been tried and validated by Khaparde and Pradhan (2009). Termed as 'guided problem solving' approach, an experiment is posed as a problem to be solved by the students. A range of conceptual understandings, experimental skills as well as attitudinal and affective factors are drawn in to evolve a procedural understanding required to carry out the problem solving act. Interestingly, the proposition does not seem to be debated and discoursed in the IAPT forum as yet.

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[15] In fact the four such experiments were presented by the physics teachers from Midnapore at the 28th National Annual Convention of IAPT, October 26-28, 2013 at St Paul's Cathedral Mission College, Kolkata. See—"Design and Solution of Numerical Problems in Physics through Experiments "followed by the names of the domain, for instance 'mechanics'.

Reappraisal and Reorientation of IAPT

Around 1994-95, most of the programmes vis-à-vis textbook writing, NSEP and NGPE, Centre for Scientific Culture (CSC), large scale orientation programmes for secondary and undergraduate teachers on experiment based teaching of concepts etc., of IAPT had already been conceived or to a significant extent executed. This also happens to be the time when the IAPT fraternity needed to intensify their engagement as well as generate more funds to carry out its activities.

Assured of the relevance and timely completion of the IAPT's projects, funding agencies (for instance, NCERT, DST and MHRD) supported the programmes undertaken by the association.[16] The MHRD funded the formation of CSCs and teachers orientation programmes. Further support to carry out programmes of the association was not forthcoming for some time and this deterred further expansion of its work. Khandewal's letter to then prime minister of India (P. V. Narsimha Rao) stands testimony of this fact. He lamented why the government of the day was underestimating IAPT's potential in the renewal of physics education in the country (Khandelwal 1997, 40).[17]

IAPT also thought of extending its mandate to post graduate education (Hans 1988, 2; 1995). Since the Indian Physics Association (IPA) was already working at the postgraduate and research levels, Khandelwal argued to restrict IAPT's involvement to undergraduate stage (Khandelwal 1994, 324). Pedagogy was another area of concern for the IAPT. Significant developments in science studies, psychology of learning and physics education research produced alternative perspectives on concept formation, problem solving or mathematical modelling in physics. IAPT largely remained untouched by these developments. It appears to be caught up with the pedagogical

[16] DST stands for Department of Science and Technology, Government of India.

[17] The letter was possibly prompted by the rejection of IAPT's request for the grant of funds worth Rs. one crore for expanding the work on centres of scientific culture (CSC).

perspective emerging during curricular reform period in 1950s and 1960s—i. e. development of Berkley Physics and PSSC.

Babulal Saraf was the first president of the association and the responsibility to steer the association fell upon him after Khandelwal's demise in February, 1996. Due to his interest and exemplary work on physics education in India, he was considered the best person on whom fellow members could repose their faith and come together as a cohesive unit. Though not tenured as president this time, his mere presence was a source of inspiration for the members. In the meantime (1995-1999), the large scale orientation programmes for undergraduate and secondary teachers in teaching through experiments were completed. This activity became a feature of IAPT's work at the national and regional levels (by regional councils), in addition to the activities of Anveshika, Centre for Scientific Culture (CSC) and C. K. Majumdar Workshop etc.[18] A version of the project was reconceived and executed again during in 2008. Association had the requisite resources deriving from the revenue earned in NSEP and NGPE and to some extent the grants received from various agencies and individuals. The publication of the journals *Physics Education* and *Prayas--Students' Journal of Physics* from 2001 and 2004, respectively, became financially viable.[19] A new generation leadership emerged in Y. K. Waghmare, H. S. Virk, B. A. Patki, Satya Prakash and H. C. Pradhan—the successive presidents of the association from 1999 onwards. During their tenures IAPT confined its work within achievable limits.

Anveshika and Related Work on Experiments

The creation of Anveshika in 2001 as a school physics laboratory at the SGM School Kanpur was another landmark in the association's attempt to base

[18] Refer to footnote no. 124, page no. 123 (C. K. Majumdar Workshop)

[19] In a similar vein IAPT has been supporting *Prayas-A Students' Journal of Physics*. *Prayas* is the initiative of students from Indian Institutes of Science Education and Research (ISSER) from Kanpur, Kolkata, Bangalore, Pune and Chandigarh and National Institutes of Science Education and Research (NISER), Bhubneswar, respectively. The journal came into existence on 1st January, 2004 (Satpaty 2008).

physics pedagogy on demonstrations and experiments. R. N. Kapoor's eye for detail coupled with unprecedented material and infrastructural support from the founder of the SGM-school, Ram Narayan Aggarwal and his successor, created an environment for the improvisation of demonstrations and experiments.

Using Anveshika as a platform, H. C. Verma developed a series of orientation programmes for teachers. Fellow IAPT members and interested agencies came forward to support the initiative. This has inspired the replication of Anveshika in different parts of the country. Now there exists a National Anveshika Network of India (NANI).[20] Other activities such as National Competition for Innovative Experiments in Physics (NCIEP) and a number of locally organised workshops on physics experiments across the country under IAPT's banner received encouragement partly due to Anveshika and its networking activities.

Over the course of time, work on devising and employing experiments in instruction became popular amongst IAPT fraternity. Teachers on their own began to design and improvise experiments. Competitions on manual and computer-interfaced experiments (NCIEP and NCICP) have provided them with a forum and incentives. Evidently, the movement for the popularisation of experiments in concept formation is building up across the schools and colleges of the country. Like with other cases, research based documentation of the impact of these experiments in enhancing conceptual understanding is either taken for granted or probably not thought of.

Pedagogical Developments in Physics

The evolution of modern physics education has its beginning in the curriculum reforms of the 1950s and 1960s. Broadly, physics instruction was viewed in inductivist terms at the lower end of school education and

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[20] Refer to chapter 5 (table 5.1, page no. 155) for the lists of the upcoming Anveshik'a under NANI. Experiments in the upcoming Anveshikas are aligned to school physics. Experiments in the upcoming Anveshikas are aligned to school physics.

deductivist at the higher one. The underlying assumption driving these developments was that having exposed students to an inductive approach, they could make a transition to the deductive approach during the secondary stage. The inductive approach was largely as unguided inquiry or discovery at the elementary stage and emphasised building concepts from observations and experiments upwards at the secondary level. The approach failed and guided inquiry was recommended. In the light of the developments in the philosophy of science and cognitive psychology during the 1970s, the curricular discourses on the methodology of physics instruction weighed in favor of the deductive illustration of concepts and theories. It was contended that before being able to conduct inquiry, students must have a conceptual and theoretical understanding at their disposal and unlike scientists its acquisition requires advancement through several grades and stages of education (Kreitler and Kreitler 1974; Hodson 1996; Millar 2004). This led to formalistic and deductive illustration of concepts and theory complemented by their verification by experiments at the introductory stage. With the course of time instruction relied heavily on the logical construction of axioms to form concepts and the derivation of mathematical expressions. Experimental activity was subsumed by concepts and theories so formed (Hestenes 1987; Koponen 2007). Apparently, this demands considerable ability for abstract thinking on the part of the students.

As the bulk of what Shulman (1986) termed as pedagogical content knowledge (PCK) of teachers lies tacit, it became a matter of convenience for teachers to deliver content in a deductive manner. This gets amply revealed when they derive formulae, equations and engage in problem-solving. Probably teachers in general reproduce the deductive approach they acquired as students (Hestenes 1987; Redish 1998). Moreover, as physics researchers they are more in tune with hypothetico-deductive thinking and habitually, tend to transmit it through their teaching. This pushes the emphasis on concept building through demonstration and experiments on the back burner (Hestenses 1979, 1987; McDermott 1991, 1993; Rief 1996; Redish 1998).

Physics Education Research (PER)

As mentioned in the preceding paragraphs, advancement over inductive rediscovery of scientific conception through deductive approach in itself did not enable students learn concepts as envisaged. Students' phenomenological experiences were seen to impede the acquisition of scientific conception. Lack of thier addressal turned out to be a missing link in the learning of physics. Pre-scientific conceptions are used to interpret day to day life phenomenon by the students. These stand in sharp contrast to scientific conceptions and offer resistance in the acquisition of the latter. Students continue to make sense of phenomena through these conceptions (Driver and Easley 1978; Carey 2000). Consequently, science educators were compelled to address the problem (Ozdemir and Clark 2007). Viewing them as misconceptions or deficits in the initial years of the research proved unproductive. Now the focus turned on to probe deeper into their elemental nature and find the ways to transform them into the scientific conceptions (diSessa 1993, 2006; diSessa and Sherin 1998; Vosniadou 2002). The work is inconclusive as yet.

Following the lead taken by science educators during the 1970s, physics educators from Physics Departments at the Universities also took up the task of exploring and transforming pre-scientific conceptions into scientific ones. In fact they moved a step ahead of their counterparts in science educators (in Department of Education). Having explored large numbers of pre-scientific conceptions, physics educators reframed them into qualitative questions in concept inventories (CIs) to diagnose students' conceptual difficulties in instructional settings. This increased the precision and accuracy of the assessment of students learning. The outcome of conceptual inventories gave rise to the development of well-validated instructional modules (Libarkin 2008; Cummings 2011; Hake 2011; Docktre and Mestre 2014).[21]

According to MeCdermott (1991, 1993), physics instruction world over fails in helping the majority of students make the transition from concrete to abstract thinking. The problem lies with the lack in quality and quantity of concrete experiences through demonstrations and experiments. Falling short of these experiences instruction does not help students make the transition to hypothetical thinking in tune with the deductive approach. Hence there arises the need to enhance concrete thinking through demonstrations and experiments, particularly at the school level. When students have reached an optimum level of development in concrete thinking there is a progressive shift towards abstract thinking through secondary, introductory and undergraduate levels. Hence, what is felt to be missing in the curricula more than anything else is the well-equipped laboratory with a large numbers of improvised and refined experiments to mediate synergetic movement across the spectrum of concrete-abstract thinking. This implies that physics educators need to demonstrate explicitly before the students the process of converting experimental data into laws and mathematical equations—the hallmark of abstract thinking in physics (Hestenes 1987, 2006; McDermott 1993; McDermott and Saffer 1998; AAPT 1997, 2014; Koponen et al. 2003; Halloun 2007).

Precisely, it is here that physics instruction fails massively. Instruction in general does not enable students to bridge the gap caused by the inductive and deductive divide. Instead of a judicious and discursive movement across the concrete-abstract spectrum, there has often been the tendency to emphasis either hands-on experiences aimed at concept-formation at the elementary and secondary stages and overwhelming shifts towards deductive illustration at senior secondary and undergraduate levels. Rather than addressing the

[21] Refer to chapter 2, section 2.5.1 and 2.5.2

question what does it need to make the transition from inductive to deductive reasoning, it is taken for granted (McDermott 1991).

As practitioners, teachers are supposed to have a deeper understanding of their discipline and are expected to explicate theories and concepts in a clear and comprehensive manner. Moreover, majority of physics teachers have yet to integrate their tacit understanding of physics with the emerging disciplinary developments in philosophy, cognitive sciences and SER or PER. 'Conception' is termed to have a wider meaning than the prevalent notion of 'concept' in the learning of science. Rather than having an independent existence, conceptions are seen symbiotically embedded in a 'conceptual ecology'—a complex of ontological, epistemological, anomalies, analogies and metaphysical beliefs. The lack of dialogic interaction with teachers makes students unaware of their conceptual ecology, its elements and fundamental assumptions. The conceptual ecology shapes the minds of students (Posner et al 1982). With a deficient meta-cognitive awareness of their conceptions, they face obstacles in learning physics. In other words, in order to comprehensively and efficiently facilitate 'conceptual change' in students, they need to develop a deeper understanding of the nature of science or physics (NOS or NOP). A well-explicated conceptual-ecology of physics (or NOP) is supposed to help students contrast and resolve inherent inconsistencies in their conceptions (Strike and Posner 1992). Succinctly, developing meta-theoretical understanding of physics would help students acquire a deeper and wider understanding of physics (Duit and Treagust 2003).

To a significant extent, David Hestenes and colleagues (Wells, Swackhamer and Halloun) seem to resolve the problem. The group led by Hestenes is credited for creating a new tool in PER under the rubric of Force Concept inventory (FCI) for mechanics as well as for producing an alternative instructional module based on model-making activity.[22] Besides reviewing the structure of physics for a long time, Hestenes has been actively updating himself about developments in philosophy and cognitive science as well as integration of these insights in science education. This interdisciplinary engagement integrates relevant ideas in proposing and validating 'Modeling as Instructional Module' (Hestenes 2006/2008). This certainly does not mean that other physics faculties did not produce advanced and well validated instructional modules. As mentioned earlier (chapter 2) there is a large array of concept inventories and the related instructional modules developed by several of the physics educators. While addressing specific instructional problems and in combination, they give rise to a holistic instructional perspective on physics instruction. Unlike science educators they have not installed a comprehensive research programmes on producing new material on NOS and in Posner et al terms are not explicit in addressing "conceptual ecology" of physics. This is their limitation.

Hestenes (1987, 2006) appears to move ahead in theorizing the process of conceptual change in physics students. According to him, the problems students confront are not only because of their pre-scientific conceptions but also due to the prevalence of inadequate or flawed way of organizing content around concept formation and over reliance on its deductive illustration. To take a concept as the unit for organizing content is a major fault line in traditional pedagogy and needs to be replaced by 'model building' as the appropriate unit of oranisation and presentation of content. Model-making is an intermediate process between concept and theory building (Hestenes 1987; AAPT 1997, 2014; Halloun 2007). When modelling and more so mathematical modeling is taken as the core for organizing content, the dictomy between experimental activity and mathematical equations in traditional instruction becomes evident. In a simplified version, modeling begins at the stage of data generation through experiments and can lead either to its direct conversion

[22] Refer to Hestenes, Wells and Swackhamer, "Force Concept Inventory" (1992).

into mathematical formulae and equations or gives rise to theoretical assumptions and axioms. Logico-mathematical reconstruction of axioms gives way to theory building as reflected in traditional pedagogy. Theoretical assumptions and mathematical equations when put together leads to theory building. New models (theoretical models) are extracted from theory and subjected for empirical validation through experiments and observation again. This completes the cycle of the model-building process in physics. From the pedagogical perspective, revisiting the whole modeling cycle reveals the whole set of gaps and tacit assumptions left unaddressed in traditional instruction. As concepts are the constituents of models, inherently conceptual learning is subsumed in the model-building process. Moreover, rather than concepts, models are termed as the appropriate unit of problem-solving in physics. Having made structural and procedural changes in favour of model-building, the approach claims to offer solutions for seemingly insoluble problem of 'problem solving' in physics instruction.[23]

The NOS provides a framework to embed and relate concepts. In order to bring about deeper understanding of concepts, a meta-theoretical understanding of this relationship is inevitable (Posner et al. 1982; Matthews 1992; Duschl 2008). Having involved in the discourses and research in the fields for two-three decades, science educators are closer to a consensus on the definition and content on the nature of science elements vis-a-vis role of empirical evidence, models, idealisation, scientific method and creativity, theory formation etc (Leederman et al 2002; Matthews 2012). It is likely that the entanglement of nature of science elements with concepts, laws and principles of physics would be emphasised to usher in a deeper understanding of physics in students (Posner et al. 1982; Strike and Posner 1992). It is interesting that physics educators so far do not seem to evince interest in this domain.

[23] Kurki-Suonio (2010) has developed a similar approach by working for over more than three decades. Unlike Hestenses, this approach avoids the use of theoretically loaded terms. The approach is termed the 'Perceptional Approach'

Physics Pedagogy in India

As mentioned earlier, the pedagogical move widespread within IAPT circles goes back to the pioneering experiments led by Babulal Saraf during the ULP project at Rajasthan University in 1970s.[24] In Saraf's view the control and variation achieved through highly refined experiments provides the real experience for grasping the meaning and relationship among physical quantities. The data generated from experimental activity when plotted graphically can approximate and disclose the abstraction and idealization of the equations and laws of physics. For instance, plotting the Inductance (L)-Capacitance (C) and Resistance (R) (or LCR) curve from the data generated from experiments, should be equally valid way to teach and learn concept taught in the theory class. This speaks volumes about his ideas.[25] The emphasis on the role of experimental activity is to illustrate how these concepts and theories can also be built upward from experimental activity. Interestingly, he did not translate his view into instructional module and was probably untouched by the contemporary developments in the field of physics education. A detailed, elaboration could have helped popularize Saraf's views within IAPT and other pedagogical circles.

Like Saraf, Khandelwal was a staunch proponent of the enhanced role of experiment in physics instruction. He worked with Saraf in ULP in Rajasthan University during the late 1970s. Besides contributing in the book series-- *Physics through Experiments* brought out by ULP at this place, he has a book entitled *A Laboratory Manual of Physics for Undergraduate Classes* in his credit.[26] In contrast to Saraf, Khandelwal was vocal in proposing and popularsing his view on experiments. According to him, physics teaching is dominated by the

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[24] Refer to the *physics through experiments* (1978, 1979) and conclusion of the work in the seminar from Dec 29, 1983-Jan 2, 1984.

[25] Expressed in the preface of S. Lokanathan and N. K. Sharma, eds., *Proceedings of the International Conference on the Role of Laboratory in Physics Education*," (The Department of Physics and Centre for Development of Physics Education: University of Rajasthan, 1984): 83-90.

[26] Khandelwal was one of the authors of the second volume of *Physics through Experiment* (1979). And the title of the book written by him was *Manual of Practical Physics*. See the related references.

direct introduction of concepts through derivation of mathematical equations and formulae and providing physical interpretations by performing verificatory experiments to obtain final value of physical quantities. As a matter of fact, it leaves out a range of perceptual experiences or physical behaviour and meanings underlying theoretical concepts. Thus rather than limiting the role of experiment to verify a theory or obtain the value of a physical constant through tailor-made experiments, students need to be involved in generating a large amount of data to form a store house of perceptual experiences or what he calls physical intuition. When data is represented graphically and symbolically to form mathematical equations, it helps in building concepts in a way missed by the verificatory experiments (Khandelwal 1984, 83-90). He suggested generating experimental data beyond the confines of the ideal curve constituting a scientific law and wait for introducing it in higher courses only. For instance, experiments need to be extended beyond 'simple harmonic motion' to the non-linear range. And similarly, with various forms of oscillatory motions such as coupled, damped, forced oscillation etc (Khandelwal 1985).[27] Rather than simply experiment, he advocated the case for 'concept centred experiments' (Khandelwal 1987, 109-113).

Exclusively good work on experimental activity in the ULP project triggered the popularisation of experimentation as a methodology of teaching physics through its various programmes and activities vis-à-vis CSC, Anveshika, NSEP and NGPE Part-C etc. On the other hand no critical debates and developments occurred in other segments of physics pedagogy. None of the programmes at the national level addressed the conceptual and logico-mathematical component of pedagogy (Joshi and Tillu 1989). Loknathan and Sharma, other co-workers with Saraf in Rajasthan, exhorted their fraternity to produce historical accounts where experiments played a crucial role in

[27] Discussed in the preface of the book entitled *A Laboratory Manual of Physics for Undergraduate Classes* published in 1985.

bringing about breakthroughs in physics.[28] Interestingly the advocates of experimental activity and logico-mathematical procedures worked together in the production of the *World View of Physics*. Khandelwal favoring experimental activity and A. W. Joshi, bringing forth the lack of work done in conceptual and logico-mathematical facets of physics pedagogy by Indian physics education community. Much felt out gap in the logico-mathematical facets, however, was left unaddressed. It was argued that non-mathematical components are more important at the introductory stage of physics education the book is meant for.

Latter on in 2008, A. W. Joshi along with a group of fellow teachers from Pune University organised a training programme for B.Sc. students on the relationship between physics and mathematics vis-a vis hypotheis, postulates, models and approximations (Joshi 2008, 240-245). In a way this can be termed as a step ahead in explicating the process of matehmatisation traditionally left unaddressed in Indian undergraduate classrooms. On the other hand Rakesh Popli attempted to reconceptualise physics pedagogy along the lines of PER to some appreciable extent. While advocating the 'phenomenological approach' he appears to support the enhanced role of experiment in physics instruction.[29] In his scheme, meticulously accurate experimental data when plotted graphically should lead to mathematical equations taught in theory. The idea is reminiscent with what was, succinctly proposed by B. L. Saraf way back in 1979 or D. P. Khandelwal in 1984 though imbued with the scientific approach in PER this time. Besides proposing the phenomenological approach, Popli in the years 1999, 2000, 2001 and 2002 also produced a detailed analysis and solutions for the conceptual difficulties students confront while making sense of a host of concepts from dynamics and

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[28] See the second preface in S. Lokanathan and N. K. Sharma, eds., *Proceedings of the International Conference on the Role of Laboratory in Physics Education*," (The Department of Physics and Centre for Development of Physics Education: University of Rajasthan, 1984): 83-90.

[29] The term 'phenomenology' has been employed in PER to denote the development of perceptual experiences through observation and experiments. Refer to diSessa (1993) and Kurki-Suonio (2010) for the expanded understanding of the term in PER.

electromagnetism at the introductory level.[30] Desai (2004) appears to reinforce the ideas of his fellow members. In his view the lack of understanding of the mathematical equations and formalism in students was the result of the lack of exposure to rich experimental activities. Similarly, other members have just referred to scientific modelling as a bridging process between experimental activity and mathematical equations (Raman 1987, 33; Gambhir 2006, 342; Joshi 2003, 272).

History and philosophy of physics (or science) to some extent happens to be the area of interest for IAPT. For instance the articles by Joshi and Khandelwal (1989) on philosophy of science and its instructional implications in the first volume of *Horizons of Physics* or Rajagopal (1996) and Desai (2003) evoking developments in the discipline and making a case for evincing interest in it by the fellow members, reflects the preliminary stage of IAPT's engagement. This implies that IAPT members are far from evolving instructional frameworks for a deeper understanding of physics inherent in NOS perspective or 'conceptual-ecology' proposed by Posner et al (1982) or Lederman group (2002) and Michael Matthews (2012).

The journal of *Physics Education* offers another arena where the larger physics education community in India showcases its pedagogical engagement. Bibliometric analysis of the literature reveals that the elaboration and illustration of theory via conceptual, logico-mathematical (axiomatic), historical and applied viewpoints has been the major preoccupation of the authors. The objective of these publications is to enhance the knowledge horizon of the readers as well as the enrichment of the textbook content. In addition to this, literature from the contemporary developments in the discipline and individual researches in physics constitutes a significant segment of this literature. The bulk of the literature appears to be reproduced

[30] Sharma and Ahluwalia (2011) from the department of physics Himachal Pradesh University have recently published some work on PER.

from various sources and in some cases the element of novelty has come in reformulation of an equation or solving a problem.

The expository literature seeks to identify and address the conceptual difficulties faced by the students by clarifying the qualitative (non-mathematical), epistemological, ontological and historical dimension of concepts and theories. In this sense though not integrated in a theoretical perspective, the publication comes close to the work conducted in science and physics education research. Moreover it appears to bring forth these strands of learning difficulties in clearer terms than what is revealed in IAPT's work. Large number of such problems and attempts of their addressal from quantum and other domains of higher physics is the area where the publications in the journal moves ahead of PER. In few cases, this is supplemented by the 'teaching acts' demonstrating the resolution of conceptual difficulties. Occasionally, intimations to conduct analysis of mathematsation in physics or philosophising the nature and impact of physics have also appeared (for instance Eghuanoye 1998). Still far from being disciplinary rigorous, this does not appear to be pedagogically amenable at this stage.

Like IAPT, designing and improvising manual and computer-interfaced experiments, has been another area of concern for the larger physics education community. The literature reveals that experiments are both a modification of existing ones as well as incorporation of novel features. In order to encourage teachers (readers) to make the idea of 'concept centred experiment' an integral part of their teaching, publications under the rubric of 'Physics through Teaching Laboratory' (PTL) and Teaching Concepts through Laboratory (TCL) were initiated (for instance Saraf and Khandelwal 1991). Occasionally tendency for philosophical reflections on physics, life, society and its relationship is also deliberated by the authors. As far as formal research into the nature of physics is concerned, they stand far a distance from it. A small fraction (3.47%) of PER appearing in the journal has come either from the departments of education or Homi Bhabha Centre for Science Education (HBCSE). Disproportionally high quantum of publications from Pune University (26%) or the state of Maharashtra (38%) puts a question mark on the all India participation of physics teachers and researchers in the renewal of physics education.

Concluding remark

Voluntary work of physics teachers is at the centre of IAPT's involvement in physics education. As practitioners, teachers have a vantage point in having tacit understanding of the problems and challenges facing physics education. Consequently they also have the concern and urge to resolve the problem. When supported, their potentialities can be tapped in producing real solution. Coming together of them from colleges, universities and school across India as an association is an expression of this concern (IAPT 1984, 2-3). However, it was not the first time physics teachers reflected upon and framed policies and programmes for the renewal of physics education. Precedence was set by the Srinagar Conference during 1970 and taken forward during ULP and COSIP projects. Apparently the objectives set by IAPT were in continuation of this work. Closer examination suggests that be it Srinagar deliberation, ULP and COSHIP projects or IAPT, they looked at the curricular reforms during 1950-60s i. e. *PSSC* and *Berkley Physics Course* as the models worthy of emulation (Saraf in the prefac of Saraf et al. 1979; Khandelwal 1986, 30, 302; Biyani and Tutakne 1989). This implies that foundation on the didactics of the yesteryears is evident in the objectives laid down by the association.

Clearly understanding of IAPT's pedagogical stance requires the understanding of the pedagogical reconstruction that took place during curricular reforms of 1950-60s. As mentioned earlier (in chapter 2), logical reconstruction of concepts, laws, principles and theory was adopted the principle to organize the curricular content and methods. The mathematical formalism related physical phenomenon to theory and provision was made to solve a large variety of problems following the assimilation of conceptual structure of physics.[31] Significant thrust was placed in the formation of concepts via demonstrations and experiments (Hodson 1996; Schaim 2006; Duschl 2008).

While imitating scientists, discovery of concepts by students was adopted as a method to learn physics at lower grades of school science, the results proved contradictory (Hodson 1996; Millar 2004). At secondary stage logical reconstruction of concepts and theory dominated the instructional practice, large scale deployment of demonstrations and experiments to illustrate the concepts complimented the deductive learning of physics (Little 1959; Daeschner 1965). With the course of time logical building of concepts acquired the predominance and illustration of concepts got restricted to the verficatory experiments (Koponen 2007, Kurki-Suonio 2010). This gave rise to the widening of inductive-deductive divide in instructional practice responsible for the much of the ills in the instruction. As deductive illustration of concepts acquired the centre stage, physics instruction became lopsided. Without optimum quantum of concrete experiences in demonstrations and experiments, students were expected to think abstractly as demanded in deductive illustration of concepts and theory (McDermott 1990, 1993). In nutshell, the pedagogical reconstruction required bridging the gap between concrete-abstract or inductive-deductive thinking to learn physics well.

Much of the target of Srinagar deliberation, ULP and COSIP projects or IAPT was to bridge the concrete-abstract or inductive-deductive gap, hence the reemphasis on the role of experiments in demonstration or illustration of concepts. 'Concept Centred Experiments' was coined to shift balance towards concrete or phenomenological thinking rooted in experiments and demonstrations in majority of the programmes vis-à-vis CSC, NSEP and NGPE, Anveshika, teachers' orientation or NCIEP and NCCAP IAPT undertook (Khandelwal 1987, 109-113; Joshi 1999; Datta 2001). Though conversion of real (extracted on the spot) experimental data into laws and

[31] The form of curricular organization continues even today.

equations of physics are often talked about, it is hardly revealed in activities. Rather than displaying the processes of modeling or idealization inherent in mathematisation of experimental data, it happens to be limited to the qualitative exhibition of the physical phenomenon or routine fitting of data into mathematical formulae and equations. It lacks in a well-integrated theoretical perspective and scientific evidence in enhancing conceptual understanding through experimental activity. For instance, research evidence from PER shows that demonstration experiments as such do not enhance concept formation. When tied to hypothesis formation and testing, they become pedagogically relevant (Crouch et al. 2004; Svedruzic 2008; Guemez et al 2009). No scientifically validated data is furnished by IAPT in this regard. Despite this, the movement to popularize the use of experiments for concept developments has picked up momentum via CSC, Anveshika, NCIEP, NCICP and number of locally organized workshops.

Development of a voluntary standard examination for undergraduate pass outs at national level was one of the key recommendations of Srinagar deliberation (UGC and UNESCO 1970). By developing NSEP and NGPE IAPT brought it to conclusive end. Though shift was made from the testing of facts, derivations and verificatory experiments to concepts and problem solving, pedagogically it remained in the fold of didactics. As such logico-mathematical reconstruction and final-form physics dominates the historical, contextual, processual dimensions or pre-scientific conceptions in these examinations. Had it been translated to the preparatory programme for International Physics Olympiad as was speculated during 1995, on account of the increased funds and widespread acknowledgement from national agencies, probably there have been an enhanced investment on the pedagogical renewal as is happening at HBCSE. INPOpiad at HBCSE brings in the knowledge of the physics teachers as practitioners as well as latest developments in the field of physics education i. e. PER.[32]

For over several decades' significant developments in science studies, psychology of learning, physics education research has produced alternative perspectives on concept formation, problem solving or mathematical modelling of physics. Consequently rather than having an independent existence, concepts are placed in larger canvass (Docktore and Mestre 2014). For instance, they are seen as symbiotically embedded in a 'conceptual ecology'—a complex of ontological, epistemological, anomalies, analogies and metaphysical beliefs (Posner et al. 1982; Strike and Posner 1992). Though majority of physics education fraternity in India remained untouched by these developments, they appear to move parallel to their counterparts in science and physics education researchers. For instance, they have been insisting on the importance of the discoveries in the history and philosophy of science for science education. Without claiming for the novelty of the material, a quantum of literature has been produced by IAPT and the larger physics education community publishing in the journal of *Physics Education*. Various dimensions of theory vis-a-vis qualitative (non-mathematical), epistemological, ontological and historical perspective posing problems in conceptualization are thrown light upon. While these dimensions are integrated in a theoretical perspective in SER (or PER), it appears to be taken for granted in this perspective.

Various agencies like NCERT, DST, UGC or individual patron have been supporting the IAPT to carry out its programmes and activities. More so the bulk of the funds required is generated out of the revenues saved from the fee

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[32] For instance, texts *Training in Experimental Physics through demonstrations and Problems by* Rajesh Khaparde and H. C. Pradhan (2009) or "Shifting Grain from the Chaff: The Concept Inventories as a Prob of Physics Understanding," Vijay A. Singh (2011) reflects the scholarly engagement in physics pedagogy by them. All of them have been key persons leading the Indian National Physics Olympiad and Undergraduate Programmes in Science Education at HBCSE.
Similar work entitling "Conceptual Experiments for Physics Teaching" has recently been conducted by Paramdeep Singh (2011) in his Ph.D. work at the Department of Physics, Guru Nanak Dev University.

charged for NSEP and NGPE. However further expansion or conceptualisation of new programmes and activities require more funds to be generated. “Laboratories are built by people first, and then by finances” is the realisation dawned upon the association after over a two or more decades grappling with the problem.[33] This implies that IAPT has to keep venturing ahead amidst the lack of funds like it has been for these years and as and when its work acquires significance it is expected to attract the needed funds to expand it further.

What could then be the reason for IAPT not being able to bring out a framework document on physics teaching and curriculum at the national level? This is clearly not due to a lack of potential on the part of the members of the IAPT. The problem has been to translate their efforts into a programme at the national level. Boyer’s (1990) suggestion for undergraduate faculties to engage in the scholarship of teaching and learning in place of just teaching seems to hold true for IAPT fraternity to a large extent. In fact following science educators, a number of physics faculties across the world have already been engaging in researching the problems of physics pedagogy much before Boyer put forward his thesis (SER and PER has been discussed in chapter 2). In order to achieve this end, they also need to involve themselves with the developments in philosophy of science; cognitive psychology and any other discipline that can help deepen and broaden their pedagogical perspective. Indeed in order to complement the pedagogical renewal they have been pursuing for two three decades, they need to mold themselves with evidence based or what is called scientific teaching (Hestenes 1979, 1998, 465-467; McDermott 1990; Redish 1999). Moreover as Dushcl (2008/2010) suggests dialectical, dialogic and argument based interaction between the teachers and students becomes essential to assimilate the outcomes of SER and PER pedagogical practice.

[33] Joshi (2008), 173.

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APPENDICES

Appendix 1

IAPT's Constitution as passed in the First Annual National Convention in 1984

I. Name: The name of the organization will be Indian Association of Physics Teachers, abbreviated hereafter as IAPT.
II. Location: Till such time as alternative arrangements are made the office will be C/o Physics Department, Indian Institute of Technology, Kanpur-2080016.
OBJECTIVES
The objectives of IAPT will be to upgrade the level of teaching in physics and related areas at all levels—both inside and outside the educational system—and to pool and mobilise the talents and resources of teachers for it in the national perspective.
IV ACTIVITES
The activites of IAPT will include:-
(a) Preparing high quality teaching material on physics and related areas, like books, monographs, audio visual aids, etc.
(b) Evaluation and development of laboratory and demonstration equipment and planning of comprehensive lab programmes.
(c) Holding conferences, seminars, workshops, reorientation programmes etc., for teachers.
(d) Enhancing public knowledge of and interest in physics and related areas through radio and TV talks, public lectures and exhibitions, museums etc.
(e) Publishing periodicals devoted to physics teaching on a broad base—for teachers, students and the general public.
(f) Identifying and giving recognition/awards to varied talents among teachers at different levels.
(g)Maintaining a pool of information regarding the special talents and interests of its members and providing expert services of IAPT to outside agenecies for purposes such as vetting of books, reviews, translation, evaluation, conduct of apecial programs, etc.
(h)Coordinating with other national and international bodies having similar objectives, and
(i) Undertaking such other tasks as may be in conformity with the objectives of IAPT.
V. Membership
a) Any person who is or has been, a teacher of physics, or has an associated subject or who has interest in the advancement of physics teaching will be eligible for Membership of IAPT.
b) Membership fee will be Rs. 25/-per annum, and Rs. 200/- for Life Membership.
c) The year will mean a Calendar year, starting from January 1.
d) Those who pay Membership fee by December 31, 1984 will be called Founder Members.
e) An admission fee of Rs. 50/- will be payable beside the Membership fee from those who join I.A.P.T. after Dec.31, 1984.
f) Renewal fee for Membership for any year is payable before the end of April that year. Thereafter the Membership will continue without voting rights up to the end of December that year. Membership will stand cancelled thereafter and fresh Admission fee will be applicable.
VI. The Organisational Structure
a) The General Body
i) The general body will consist of all members of IAPT
ii) It shall meet once a year to receive report of accounts and working from the Executive Council and to give directions for future work.
iii) At least one month's notice will be necessary to call its meeting.
iv) The quorum shall be one-tenth of the membership on the date of the notice, or fifty, whichever is less. A meeting adjourned for want of quorum shall be called only with fresh circulation of notice and agenda, but shall not need to fulfill quorum requirement.
b) The Executive Council

i) The Executive Council (EC) shall consist of the following elected persons: Presidents (1), Vice-Presidents (4), General Secretary (1), Joint Secretaries (4), Treasurer, Members (10)
ii) The elected personnel of the EC May co-opt up to 4 members to the EC.
iii) All the executive authority of IAPT shall vest with the EC which shall meet at least three times in a year.
iv) At least 20 days' notice shall be necessary to call its meetings.
v) The quorum shall be one-third of the total membership of EC.
vi) The EC shall prepare a plan of work within the frame-work of the General Body directions, and prepare a budget.
vii) The EC shall have tenure of two years starting from 1st of January following its election.
ix) The EC shall be elected by postal ballot well before the term of the outgoing EC expires. The procedure will be as per Appendix A (to be laid down by the EC).
(C) Functions of the Office Bearers
i) The president: He shall preside over the meeting of the General Body and the Executive Council. He shall give general guidance for affairs of IAPT and shall be its principal spokesperson.
ii) The Vice-President: In the absence of the president, the senior most Vice President will fulfill his duties. Each Vice-President will also assist the President as regards general guidance for affairs of IAPT.
iii) The General Secretary: He shall be chief Executive of IAPT, responsible for maintaining records of membership, issuing notices for and maintaining the minutes of meetings and giving assistance to the President and to various Committees. He shall call the meetings of General Body and Executive Council at palaces and times decided in consultation with President.
iv) The Joint Secretaries: In the absence of the General Secretary, the senior most Joint SERETARY shall act as the General Secretary. Each Joint Secretary will also assist the General Secretary (GS) in various tasks which may be assigned to him either by the GS or by the EC.
v) Treasurer: The treasurer shall be in charge of the funds of IAPT and shall also keep the accounts. In the absence of the Treasurer the senior most Joint Secretary shall act as the Treasurer. The treasurer may give advance to various functionaries of IAPT, as necessary, but he shall ensure that regular and full accounts against these are received.
vi) Members of EC: Every member of EC shall give general assistance to the President and General Secretary in IAPT work, and also act as a communication channel between the EC and the General Body members.
VII Finance
a) Apart from the membership fee and admission fee, vide clause V, the IAPT may have one or more of the following sources of finance:
i) Periodic Grants: Sanctioned by various agencies to further IAPT objectives.
ii) Donations: Offered to IAPT by individuals for the furtherance of its objectives.
iii) Endowments: For specific purposes, like prizes, scholarships, running programmes etc.
iv) Assignment Funds: From various agencies for specific task, like writing of books, vetting of manuscripts, running of reorientation courses, establishing a museum, etc.
v) Subscriptions: For I.AP.P.T Journals.
b) IAPT shall not make any profit on its products or its services
c) None of the IAPT members or its office-bearers will be paid remuneration for IAPT work. Provided that this clause would not forbid reimbursement of expenses incurred in doing IAPT WORK (such as TA and DA), or payment of honoraria to individuals or work against specific assignments/ contracts with other agencies etc.
d) The funds of IAPT will be kept in a scheduled bank or banks as decided by the Executive Council.
e) Withdrawals from bank account shall be made under the signature of two out of three persons for amounts exceeding Rs. 1000/- (Rupees one thousand) and one out of three persons for amounts below and up to Rs. 1000/-. The authorized persons will be decided by the Executive Council.
VIII. Amendment of the Constitution

Amendments to the constitution shall be made by the General Body only if the proposed changes are circulated with the agenda and are approved by over two-thirds of the members present and voting.

IX) Dissolution

In the event of dissolution of the IAPT or its winding up, the funds and assets shall under no circumstances be disbursed among its members, but shall be transferred to any institution or institutions with objectives close to those of IAPT

Source: *Bulletin of IAPT* 1, no. 9 (1984): 30-33

Appendix 2

INDIAN ASSOCIATION OF PHYSICS TEACHERS

NATIONAL STANDARD EXAMINATION IN PHYSICS 2006-2007

Total Time: 150 minutes (A-1, A-2 & B)

PART A MARKS: 180

....

SUB-PART A-1: Only ONE OUT OF FOUR OPTIONS IS CORRECT

....

1) f E is the electrical field intensity and μ_o is the permeability of free space, then the quantity E^2/μ_o has the dimensions of
$[M^2L^3T^{-3}I^2]$ b) $[MLT^{-4}]$ c) $[ML^3T^{-2}]$ d) $[M^{-4}L^2TI^{-2}]$

2) The sum, difference and the product of two non-zero vectors 'a' and 'b' are mutually perpendicular. Then,
a) $[a \times b] = a.b$ b) $a.b = 0 \; and \; [a] \neq [b]$ c) $[a] = [b] = [a \times b]$)$a.b = 0 \; and \; [a] = [b]$

3) The particle moving along a straight line travels one third of the total distance with a speed of 3.m/s. The remaining distance is covered with a speed of 4.o m/s for the other half of the time. The average speed during the motion is....
a) 4.0m/s b) 6.0m/s c) 3.8 m/s d)2.4 m/s

4) Boy throws a table tennis ball of mass 20g upwards with a velocity of u° =10 m/s at an angle θ_o with the vertical. The wind imparts a horizontal force of 0.08 N, so that the ball returns to the starting point. Then, the angle θ_o must be such that, tan θ_o is.....
. a) 0.2 b) 0.4 c) 2.5 d) 1.2

5) A canon ball has a range R on a horizontal plane, such that the corresponding possible maximum heights reached are H_1 and H_2. Then, the correct expression for R is...
a) $(H$ b) c) d)

6) A windmill converts wind energy into electrical energy. If v is the speed of the wind, electrical power output is proportional to
a) ϑ b) ϑ^2 c) ϑ^3 d)ϑ^4

7) One end of a metallic wire of length L is suspended from a rigid support. The other end is tied to a mass less wire of spring constant K. A block of mass m hangs freely from the other end of the spring. If Y and A are the young's modulus and the area of cross section of the wire respectively, the period of oscillation of the mass will be.....
a) $2\pi(\frac{m}{K})^{\frac{1}{2}}$ b) $2\pi[m\frac{(YA+KL)}{YAL})^{\frac{1}{2}}$ c) $2\pi(\frac{mL}{YA})^{\frac{1}{2}}$ d)$2\pi(\frac{mYA}{KL})^{\frac{1}{2}}$

8) In a spring block system, length of the spring is reduced by 1%. Its periodic time will be............
a) Remain the same b) decrease by 1% c) decrease by 0.5% d) increase by 0.5%

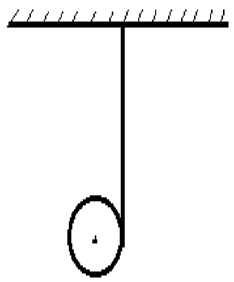
9) Heat is supplied to a diatomic gas at constant pressure. With the usual notation the ratio of heat, internal energy and wok done is...............

a) 5:2:2 b) 5:2:3 c) 7:5:2 d) 7:2:5

10) Starting from the same initial conditions, the work done in an isothermal, adiabatic and isochoric processes is in the order of................

a) $W_1 > W_2 > W_3$ b) $W_3 > W_1 > W_2$ c) $W_2 > W_3 > W_1$ d) $W_3 > W_2 > W_1$

11) A massless rope is wrapped around a ring (with a groove along its circumference) having a radius R and mass m. The ring is allowed to move downward. The linear acceleration of the ring is.........

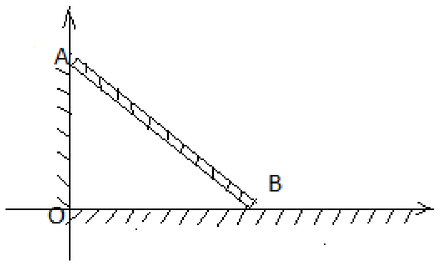


a) $^{2g}/_3$ b) $^{g}/_2$ c) $^{g}/_3$ d) g

12) A planet moving along an elliptical orbit is closest to the Sun at a distance r_1 and farthest away at a distance of r_2. If v_1 by v_2 are the linear velocities at these points respectively, then the ration of $\frac{v_1}{v_2}$ is

a) $\frac{r/_1}{r/_2}$ b) $\frac{r/_2}{r/_1}$ c) $(\frac{r/_1}{r/_2})^2$ d) $(\frac{r/_2}{r/_1})^2$

13) A rigid rod of length l is in contact with a vertical wall with its other end in contact with a horizontal floor. Point A moves with a constant velocity. The path along which the midpoint of the rod moves is...



a) A straight line not passing through the origin
b) A parabola with X and Y axis it tangents
c) A rectangular hyperbola
d) A circle of radius l/2 with its centre at the origin

14) A large tank has two holes in the wall. Hole one has a square cross section with side l and is cut at a depth h from the top. Hole two has a circular cross section of radius r at a depth of 4h from the top. When the tank is completely filled, the quantities of water flowing out through the holes per second are the same. Then, l is equal to.....

a) $\frac{r}{\sqrt{2\pi}}$ b) $r\sqrt{2\pi}$ c) $\frac{r}{\sqrt{\pi}}$ d) $r\sqrt{\pi}$

15) One mole of an ideal mono-atomic gas expands till its temperature doubles under the process V^2T=constant. If the initial temperature is 400K, the work done by the gas is....

a) 000R b) 200R c) -200R d)Intermediate

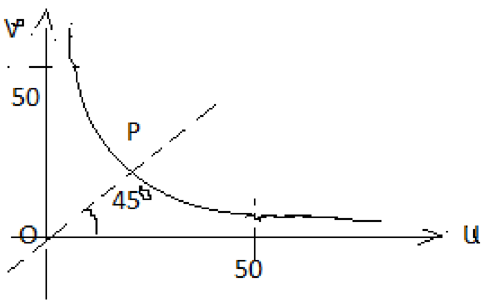
16) The function representing a progressive wave is…….
a) $y = 2\sin(4t + 3x)$ b) $y = e^{i[4+(4t-3x)]}$ c) $y = [4t - 3x]^{-1}$
d) $y = [4t - 3x]$

17) The general solution of a wave equation is written as y(x, t)= f (ax±bt). Then, the speed of the wave is given by ……..
a) $^a/_b$ b) $^b/_a$ c) ab d) $(^b/_a)^{1/2}$

18) A point source of light is placed at a depth of 'h' below the surface of water of refractive index μ. A floating opaque disc is placed on the surface of water so the light from the sources is not visible from the surface. The minimum diameter of the disc is

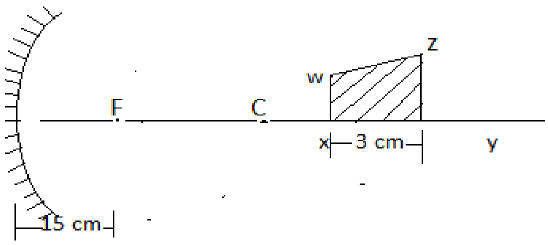
a) $2h/(\mu^2 - 1)^{1/2}$ b) $2h\ (\mu^2) - I)^{1_2}$ c) $h/[2(\mu^2 - I)^{1/2}]$
d) $h(\mu^2 - I)^{1/2}$

19) In case of the spherical mirror of focal length f, a graph is plotted as shown. The coordinates of the point P are… ………



a) $(2f, 2f)$ b) (f, f) c) $(\frac{f}{2}, \frac{f}{2})$ d) $(4f, 4f)$

20) Referring to the figure, the image of the quadrilateral XYZW placed in front of the concave mirror



a) Will be congruent to itself b) will be similar to itself c) will neither be congruent nor be similar d) will be non of the above

21) A thin symmetrical double convex lens of refractive index μ^2 (1.5) and μ^1 (1.4) to the left and another medium of refractive index μ^3 (1.6) to the right. Then, the system behaves as…
a) A convex lens b) a concave lens c) a glass plate
d) a convexconcave lens

22) Two linear polarisers are crossed at an angle of 60°. The fraction of intensity of light transmitted by the pair is.......
a) 1/4 b) 1/8 c) 3/8 d) 1/2

23) A body of density p enters a tank of water of density q (q is greater than p) after falling through a height h. Find the maximum depth through which it sinks in the water?

a) $h\rho_1\ l(\rho_1 - \rho l)$ b) $h\rho_1 l(\rho_1 - \rho)$ c) $h\rho l\ \rho_1$ d) $h\rho_1 l\rho$

24) The two pipes are each 2 m long. One is closed at one end and the other is open at both ends. The speed of sound in air is 340 m/s. The frequency at which both can resonate is

a) 340Hz b) 510 Hz c) 42.5 Hz d) non of the above

25) In case of an electromagnetic wave, the radiation pressure has the dimension of

a) Intensity b) energy density c) energy flux d) energy per unit area

26) A cylindrical vessel contains a liquid of a density ρ up to a height h. A frictionless piston of mass m and area of crosss section A is in contact with the upper surface of the liquid. There is a small hole at the bottom of the vessel. The speed with which liquid comes out of the hole is

a) $(2gh)^{1/2}$ b) $[2g\left(h + \frac{m}{\rho A}\right)]^{1/2}$ c) $[2g\left(h + \frac{m}{A}\right)]^{1/2}$ d) $[2gh + \frac{mg}{\rho A})]^{1/2}$

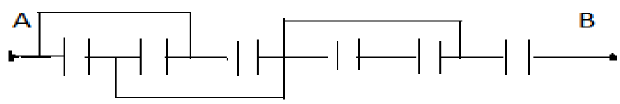
27) You have been provided with four 100 Ω (ohm) resistors each with a tolerance of 2%. A number of ways in which these can be combines to have different equivalent resistances is

a) Seven different combinations and seven different equivalent resistances
b) Eight different combinations and seven different equivalent resistances
c) Nine different combinations and eight different equivalent resistances
d) Ten different combinations and nine different equivalent resistances

28) In the above problem, the tolerance of the equivalent resistance will be

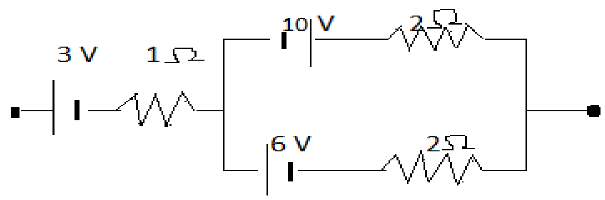
a) more than 2% b)equal to 2% c) less than 2% d) any one of the above depending upon a particular combination

29) If each of the capacitors has a capacitance of 1μF, the equivalent resistance between points A and B is



a) 6 μF b) 1/6μF c) 3/4μF d) 3/10μF

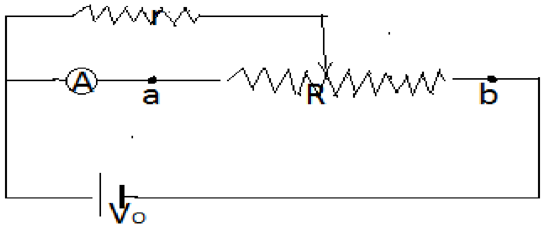
30) The e.m.f. and the internal resistance of a battery equivalent to the combination of batteries (in series with their internal resistances) shown in the figure is..................



a) $7V\ and\ 2\Omega$ b) $13V\ and\ 5\Omega$ c) $1V\ and\ 2\Omega$ d) $1V\ and\ 1\Omega$

31) A cylindrical conductor having radius of cross section R carries a steady current I. If the distance from the axis of the conductor is r, then the magnetic field B varies with respect to r as........... a) $^{l}/_{r}$ b) $r\ for\ r < R\ as\ ^{l}/_{r}\ for\ r \geq R$ c) r d) $^{l}/_{r^2}$

32) Referring to the circuit, R is the resistance of potentiometer. As the sliding contact is moved from a to b, the reading in the ammeter will.

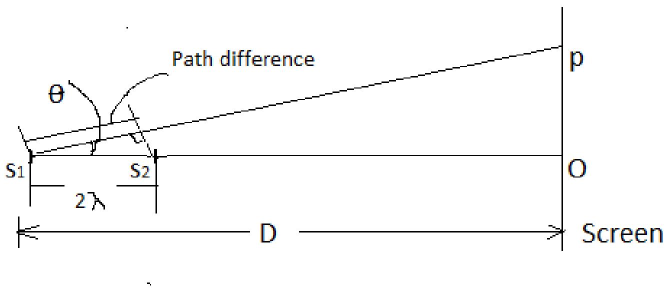


a) Increase

b) Decrease

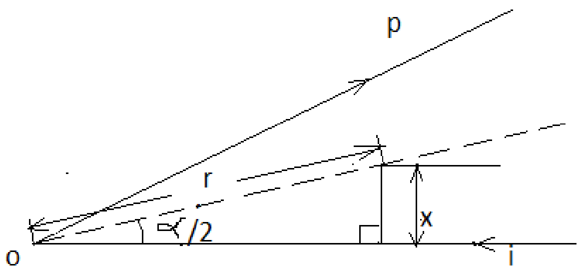
c) Initially decrease and then increase

33) Two sources S^1 and S^2 emitting coherent light wavelength λ in the same phase are situated as shown. The distance OP so that the light intensity detected at P is equal to that at O is



a) $D\sqrt{2}$ b) $D/2$ c) $D\sqrt{3}$ d) $D/\sqrt{3}$

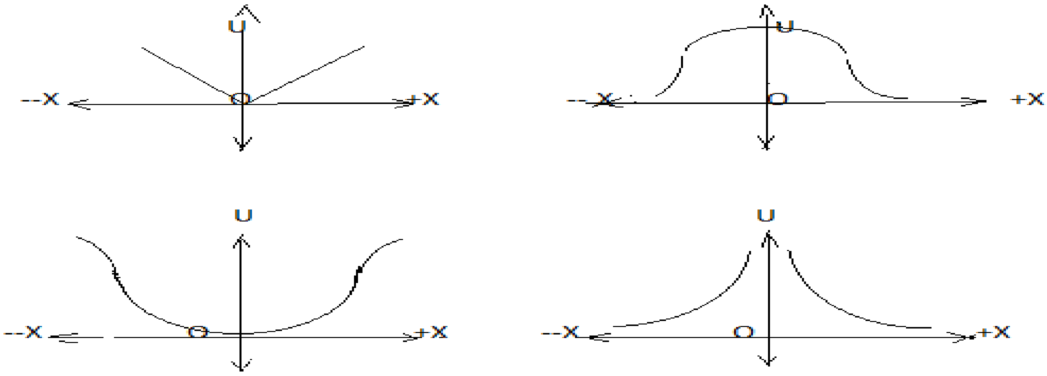
34) An infinitely long conductor is bent at a point O at an angle α as shown. The magnetic field at a point P distance r along the angle bisector is



a) $(\mu_{0/4\pi})(2ilr)[l + \csc{}^{\alpha}/_{2}]l \sin{}^{\alpha}/_{2}$ b) $\left(\frac{\mu_0}{4\pi}\right)(i/r)\cot{}^{\alpha}/_{2})$ c) $\left(\frac{\mu_0}{2\pi}\right).\left(\frac{i}{r}\right)\cot{}^{\alpha}/_{2})$

d) $\left(\frac{\mu_0}{4\pi}\right)\left({}^{i}/_{r}\right)\sin{}^{\alpha}/_{2}$

35) Four identical charges are placed at the four vertices of a square lying in YZ plane. A fifth charge is moved along X axis. The variation of potential energy (U) along X axis is correctly represented by



36) A particle having charge of +2 mC moves under the electric forces and has a kinetic energy of 5.0 J at point A. The particle passes through point B which is at a potential of +1.5 kV relative to point A. The kinetic energy of the particle in joule as it moves through the point B is............ a) 3.0 b) 2.0 c) 5.0 d)8.0

37) The wavelengths of K alpha line of X-rays for isotopes Pb 208, Pb 206 and Pb 204 are λ_1, λ_2 and λ_3 respectively. Then, what is the relationship between their wavelengths?

a) $\lambda_1 > \lambda_2 > \lambda_3$ b) $\lambda_1 < \lambda_2 < \lambda_3$ c) $\lambda_1 = (\lambda_2\lambda_3)^{1/2}$ d)$\lambda_1 = \lambda_2 = \lambda_3$

38) The transition in He^{+} ion that will give rise to a spectral line having the same wavelength as that of some spectral line in hydrogen atom is.........

a) $n = 3 \text{ to } n = 1$ b) $n = 3 \text{ to } n = 2$ c) $n = 4 \text{ to } n = 2$ d)$n = 4 \text{ to } n = 3$

39) An electron in the ground state of hydrogen atom goes to an exited state by absorbing 12.1eV energy. In the course of its transition to lower energy states, the possible number of spectral lines will be ……..

a) 1 b) 3 c) 6 d) 10

40) The activity of a radioactive substance is R_1 at the time t_1 and R_2 at a later instance t_2. Its decay constant is λ. Then,

a) $R_1 t_1 = R_2 t_2$

b)$R_2 exp^{\lambda t_2} = R_1 exp^{\lambda t_1}$

c)$R_1 = R_2 exp^{[\lambda(t_2 - t_1)]}$

d) $R_1 - R_2 = a \text{ constant } (t_2 - t_1)$

....

SUB-PART A-2

....

In question 41 to 50 any number of options (1 or 2 or 3 or all 4) may be correct. You have to identify all of the correctly to get 6 marks. Even if one answer identifies is incorrect or one correct answer is missed, you get zero score

....

41) In SI system the unit of CR^2, where C is the capacitance and R is the resistance, can be written as the units of.....

a) Henry b) Volt-Second/ampere c) Volt/ampere d) joule/ampere square

42) A particle under the influence of two SHM's moves in XY plane along a path shown in the adjacent figure. Then…..

a) The motion has the same frequencies in X and Y directions

b) Phase difference between X motion and Y motion is $(\pi/4)^{\circ}$
c) The maximum velocity in Y direction is twice that in X direction
d) Its total energy due to motion in X direction is four times that due to motion in Y direction

43) 43. Adjacent figure shows the path of a light ray as it enters from medium 1 to medium 2. Then.........
a) $\frac{\mu_1}{\mu_2} = \sin\theta_1 / \sin\theta_2$
b) any path between A and B other than the one shown in the figure would take longer time if $\mu_1 \sin\theta_1 = \mu_2 \sin\theta_2$
c) $\mu_1 > \mu_2$ if $\theta_1 < \theta_2$
d) there exists $\theta_1 > \theta_{critical}$ for which ray from A ill be totally reflected if $\mu_1 < \mu_2$

44) A particle having the mass m and charge q moves along a line under the action of an electric field E=α-βx where α and β are positive constants and x is the distance from a point where the particle was initially at rest. Then, for an observer moving with an acceleration qα/m,

a)the motion of the particle is oscillatory
b)the amplitude of the particle if α/β
c) the mean position of the particle is $x = \alpha/\beta$
d)the maximum acceleration of the particle is $q\alpha/m$

45) A source of e.m.f. having internal resistance of 6 Ω dissipates maximum power in a circuit consisting of three resistors R_1, R_2 and R_3 as shown. Then, a) $I_3 = 0.8\ A$ b)V=24V c) $R_1 = 15\Omega$ d) equivalent resistance of the circuit is 6Ω

46) A body is dropped in a frictionless tunnel imagined to be drilled along a chord of the earth. Then,
a) the motion is simple harmonic b)the force is zero at the midpoint of the tunnel c)the force is maximum but not zero at the midpoint of the tunnel d) the period of oscillation is the same irrespective of the length of the chord.

47) If I_1, I_2, I_3 and I_4 are the moments of inertia of a square plate of uniform thickness about axes 1, 2, 3 and 4 respectively as shown. Then, the moment of inertia of the plate about the axis through O and perpendicular to the plate is….
.
a) $I_1 + I_2$ b) $I_3 + I_4$ c) $I_1 + I_3$ d) $I_2 + I_4$

48) A particle moves in a straight line under the action of a constant force. Then, the graph of power developed by the force against—time is ……..

a) Time is a straight line
b) Time is a parabola
c) Displacement is a straight
d) Displacement is a parabola

49) A cell dissipates the same power across each of the two resistances R_1 and R_2. The internal resistance of the cell is

a) $R_1 + R_2$ b) $(R_1 + R_2)/2$ c) $(R_1 + R_2)^{12}$ d) $(R_1 + R_2)^{12}/2$

50) If body A of mass m strikes another body B of mass M at rest and suffers an elastic collision. After collision body A moves with one fourth of its initial speed. Then, the ratio M/m can be…….
a) 3/5 b) 3/4 c) 5/3 d)2/3

....

....

PART B MARKS:

120

....

....

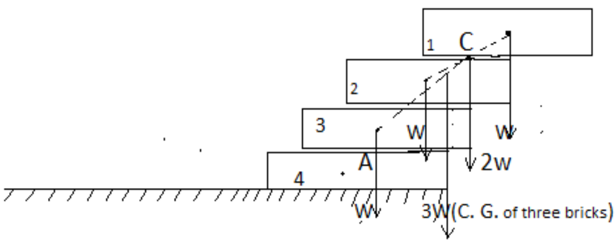
All questions are compulsory All questions carry equal marks

....

....

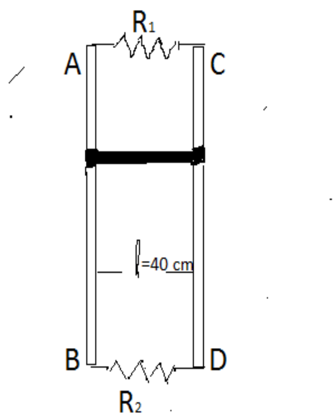
1) A car leaves point A for point B every 10 minutes. The distance between A and B is 60 km. The cars travel at a speed of 60km/hr. Determine graphically only, the number of cars that a man driving from B to A will meet in route, if he starts from B simultaneously with one of the cars leaving A. The car from B travels with a speed of 60km/hr.

2) A mason lays four bricks to make an arch so that a portion of each brick protrudes over the one below. Determine the maximum lengths of the overhanging parts when the bricks are still in equilibrium without mortar. The length of each bricks is l5 cm.

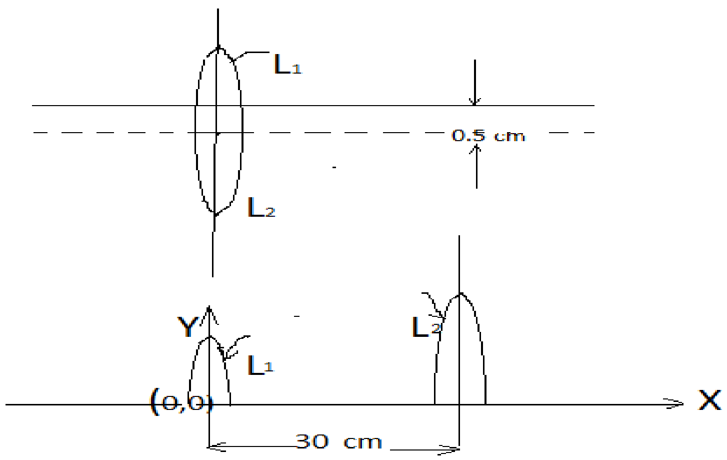


3) A uniform rope of length 12m and mass 6 kg vertically from a rigid support. A block of mass 2 kg is attached to the free end. A transverse pulse of wavelength 6 cm is produced at the lower end of the rope. Obtain an expression for the wavelength of the pulse as a function of distance x covered by it from the lower end. Hence, find the wavelength at a point of trisection from the lower end and at the top of the rope

4) Two parallel vertical metallic rails AB and CD are separated by 40 cm. They are connected at the two ends by resistances R_1 and R_2 as shown. A metallic bar of length l of mass 100 g slides along the rails without friction. A uniform magnetic field of 0.5 T perpendiculars to the plane of the rails is established. It is found that when the bar attains the terminal velocity, the powers dissipated in R_1 and R_2 are 0.50 W and 0.75 W respectively. Find the terminal velocity of the bar and values of R_1 and R_2. Neglect the resistance of the bar and the rails.

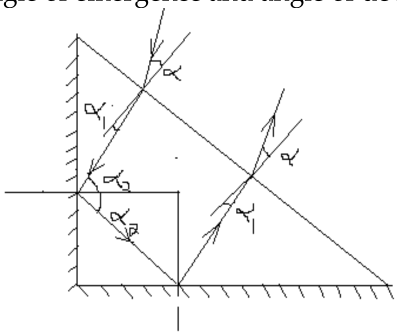


5) A thin convex lens of focal length 50 cm is cut into two pieces 0.5cm above the principal axis as shown. The parts are now placed on the X axis. Determine the coordinates of the image of an object placed at (-100, 0).

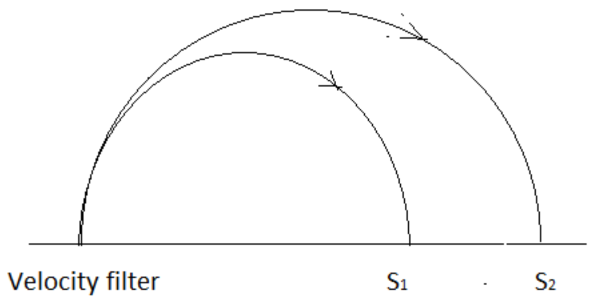


6) The ionization energy of potassium is 4.34 eV, the electron affinity of iodine is 3.06 eV. At what separation distance, will the KI molecule gain enough coulomb energy to overcome the energy needed to form K^+ and I^- ions.

7) The congruent faces of an isosceles right triangular prism are coated with a reflecting coating. A ray of light falls on the hypotenuse at an angle α. Find the angle of emergence and angle of deviation. Draw the ray diagram.

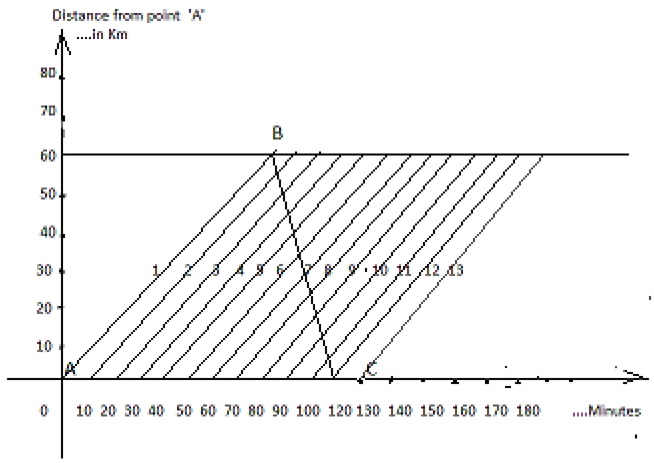


8) The velocity filter of a mass spectrometer uses electric field intensity 100 V/m and a magnetic field of induction 2×10^{-2} T. Another uniform magnetic field of induction 9×10^{-2}T perpendicular to the beam is used to deflect the beam. Ions with the same charge having mass numbers 20 and 22 pass through the filter and make a 180° turn in the deflecting field. Calculate the distance between the points S_1 and S_2.



9) A block of mass m is placed on a smooth horizontal surface. A force making an angle θ with the horizontal starts acting on the block. The magnitude of the force is constant but its direction with the horizontal changes as θ =a+bs where a and b are constants and s is the distance covered by the block. If |F|=2mb, find the velocity of the block as a function of the angle θ.

10) A highly conducting uniform sphere of thermal capacity c is heated by an electric heater of resistance R fitted within the sphere. A constant current I is passed through the heater starting at time t=0. The sphere loose heat at rate equal to k times the temperature difference between the sphere and the surrounding. The initial temperature of the sphere and that of the surrounding is 0℃. Find the temperature of the sphere (in ℃) as a function of time. After what time will the sphere attain half of its maximum attainable temperature?



Appendix 3

National Standard Examination in Physics (NSEP) Part-C

A. NSEP Part-C 1993

The structure of the examination may be changes to: Type P Items: 6 items of 10 minutes each
Type Q items: 3 items of 20 minutes each
Type R items: 2 items: of 30 minutes each
P-01. Making quick estimation of physical quantity (length, area, volume, mass etc)
P-02. Locating the Centre of mass of a card sheet (manual skills)
P-03. Drawing a capillarity from a glass tubing (manual skills)
P-04. Filling a weight thermometer at room temperature (manual skill)
P-05. Machining a plastic sheet (manual skill)
P-06. Measuring the volume of a wooden block (manual and conceptual)

P-07. Setting up a lamp-and scale device (measurement of a small angular deflections—lens, mirror, marker/scale) (setting up an apparatus)
P-08. Finding the resonant length on a sonometer (manual and conceptual)
P-09. Finding the ratio of three resistances using a voltmeter (manual and conceptual)
P-10. Finding the percentage transmission of light through a glass plate (manual and conceptual)
P-11. Finding the magnetic neutral points with a general position of magnet (manual and conceptual)
P-12. Measuring the sensitivity of a beam balance for different fulcrum (manual and conceptual)
P-13. Wiring a household circuit (manual and conceptual)
Q-2.1 Obtain a calibration graph for a water thermometer, and extrapolate it to 0°C and 100°C. (measurement and graphical display of data, interpretation)
Q-2.2 Conversion of image of an ammeter and a voltmeter (manual and conceptual)
Q-2.3 Studying the extension of a rubber string with load (open-ended, using the given material)
Q-2.4 Setting up a Prism Littrow arrangement from spectrum (setting apparatus)
R-3.1 Study of the damping in a simple pendulum (open-ended, using the given material)
R-3.2 Study of L, C, R series circuit for phasor addition of voltages, and using it to (open-ended, using the given material) deduce the parameter
Source: IAPT, "NSEP-93 Part C: Evaluation of Experimental Skills," *Bulletin of the IAPT* 10, no. 6 (1993): 180-190.

B. NSEP Part-C 1995

The examination was held on 28the May 1995 at nine centres simultaneously in the country.
Short Items P Type--7.5 minute duration --six -------10 marks each
Medium items Q Type—15 minutes duration --three—20 marks each
Long item R-Type--45 minutes duration -one -40 marks
P-1 Cut, with the help of hand hacksaw, a sheet of backlite into a triangular shape with smoothened edges (manual skills-usually this is already provided or done by the lab assistant, the necessary material was provides).
P-2 To bend a glass tube into a specific shape without sharp edges and too much curved. (Manual skills)
P-3 Using the material (test tube, a tall jar, liquid and water), determine the specific gravity of the given liquid. (To assess-knowledge of related principle, precision and accuracy of measurement (significant places of measurement)
P-4 Identify from among the given material (capacitor greater than 1 m.fd, equal to 0.05 m.fd, resistor 0.5 watt, Rheostat 9 volume control), choke coil, transformer transistor, transistor p-n-p, semiconductor diode, light emitting diode (LED).
P-5 Find the resistance of a torch bulb to the nearest significant places for very low, medium and high value of the current, and the power value for each, in a connected circuit provided.
P-6 Analyse a given data from the graph:
You are provided with a graph on which data points of the following experiment are marked. "A pendulum was started with amplitude about 75 degrees. After it settled down with about 20 oscillations, we measured the time for 10 oscillations, allowed 30 oscillations to pass through, then measured the time for 10 oscillations, and so on, till the amplitude fell to below 5 degrees. In the process about n=400 oscillations passed through. Draw the best possible smooth curve which would pass through the data points to express the smooth variation expected. From the curve, read out the time for 10 oscillations which correspond to n=240. From the graph read out the asymptotic value T_0 expected to be reached by the period T as the amplitude tends to be zero.
Q-1 To estimate the fractional heat lost to the container and the surroundings by using the given material (water being boiled on a heater, a mug, a plastic bucket and one thermometer 0.5 into 100 degrees C.

Q. 2 A projectile (a steel ball) released horizontally from a variable height h from the floor with a given velocity v strikes the floor at a variable distance x. You are to find by experiment a relation between x and h. v is kept the same during the experiment.
Q.3 To study chromatic and astigmatic error in a lens. To see whether students can get a sharp focussed image, distinguish between the red and blue mage, the white image comes somewhere in between.
R-Figure below shows one of the possible coupled oscillators, with two identical members. Pendulum AP and BQ are the identical members (having same length and mass of the bobs), and they are coupled because their support points are on a string CABD, which has a sags, the separations AB being d. When displacing any one of the bob, the oscillations are built on each of the bob, however due to coupling, amplitude of one changes at the cost of the other (i.e increase in one is followed by the corresponding decrease in other). There are only two modes of oscillations for which oscillations continue without alternative change of amplitudes of the two pendulums. Explain why normal modes occur for a two sets of displacements (displacement in the same and opposite direction) and not for the n numbers of others?
Source: IAPT, "National Standard Examination in Physics-1995: Part C-Evaluation of Experimental Skill," *Bulletin of the IAPT* 22, no. 7 (1995): 215-217.

Appendix 4

The manual for the physics laboratory-kit at CSC-Midnapore

S. No.	Demonstrations
1	Demonstration of the fact that air has mass
2	Pressure at a point in a liquid depends on depth, using water manometer
3	Preparation of a Cartesian diver and explanation of a) principle of floatation, b) Pascal's law and c) principle of submarine
4	Explanation of concept of density using a scale balance and wooden blocks
5	Experiment on the floatation of a body using a wooden block
6	Demonstration of surface tension of water using a) needle, b) capillary and d) two microscope slides along with a scale balance
7	Demonstration of the fact that liquids find its own level and the explanation of viscosity of water using two plastic bottles connected by a capillary tube
8	Demonstration of Boyl's law using plastic tube
9	Demonstration of weightlessness using plastic tube
10	Experiment with a water jet coming out of the hole in a plastic bottle containing water
11	Demonstration of the transfer of energy between two identical pendulums prepared out of marble balls
12	Demonstration of forced vibration, resonance and explanation of the principle of selecting a particular frequency from a band, using ten pendulum as visitors and one pendulum with variable thread and big bob as the exciter
13	Use of thermometer in measuring temperature-boiling point and freezing point of water and their dependence on impurity
14	Demonstration of apparent and real expansion of water, when heated, using a spirit lamp contains and plastic pipe/capillary tube
15	Demonstration of unequal thermal expansion of solids using bi-metallic plates
16	Demonstration of linear thermal expansion of solids using a liver arrangement
17	Demonstration of greenhouse effect
18	Demonstration of condition, convection and radiation of heat using a beaker, thermometer and spirit lamp

Continuation of the table

19	Preparation of a pin hole camera using a) cardboard box, b) pieces of plane mirror pasted on a cardboard
20	Formation of shadows- measurement of the height of a tree by observing the length of its water
21	Demonstration of the dispersion of sunlight using a broken plane mirror and a plate containing water
22	Demonstration of reflection of light by plane, convex and concave mirrors using laser/ordinary torch
23	Preparation of hollow prism using plane glass sheets and adhesive
24	Demonstration of dispersions of white light while passing through water using a water
25	Demonstration of scattering of light by paper sheets using a torch bulb
26	Demonstration of total internal reflection using a water prism and a laser torch
27	Demonstration of total internal reflection of light while passing through a stream of water-explanation of the concepts of propagation of light through an optical fibre
28	Demonstration of the actions (i.e. convergent and divergent properties) of convex and concave lenses
29	Preparation of Kaleidoscope
30	Use of different electric meters such as galvanometer, voltmeter, digital multi-meters etc
31	Demonstration of generation of electricity directly from light using solar cell/photo cell
32	Demonstration of generation of light directly from electricity using LED
33	Demonstration of generation of electricity directly from heat using a thermocouple
34	Demonstration of directive, attractive/repulsive and inductive properties of magnets using bar and ring magnets
35	Demonstration of generation of heat and light using torch bulb and battery
36	Preparation of an electric cell from raw materials
37	Demonstration of generation of electricity in a coil due to a moving magnet-electromagnet
38	Preparation of electromagnet and the demonstration of the role of iron core
39	Demonstration of attractive/repulsive between a current carrying coil and a ring magnet
40	Demonstration of the magnetism induced in a current carrying circular coil using a magnetic needle
41	Demonstration of attractive/repulsive between two current circular coils
42	Demonstration of the difference between direct current (dc) and alternative current (ac)
43	Demonstration of the existence of consequent pole
44	Demonstration of loss magnetic properties due to heating, using a ferric rod and a bar/ring magnet diode (LED), light dependent resistance (LDR), thermistor etc
45	Demonstration of loss magnetic property of electronic devices such as rectifying diodes, light emitting diodes (LED), light dependent resistance (LDR), thermistors
46	Preparation of a magnetic levitation set and its uses a) to induction, b) to explain working principle of a transformation c) to demonstrate attraction/repulsion between two current carrying coils (ac) and d) to demonstrate the heating effect of current
47	Demonstration of the action of basic logic gates
48	Demonstration of the fabrication of battery eliminator using a step-down transformer and rectifying diodes

Continuation of the table

	List of experiments for measurement based activity
1	Measurement of length with Vernier Scale, Slide Callipers, screw gauge, speedometer and travelling microscope
2	Use of Vernier scale: concept of moment and construction of a scale balance
3	Measurement of mass: concept of moment and construction of a scale balance
4	Use of scale balance for verification of Archimedes principle-determination of the volume of an irregular body
5	Determination of specific gravity of a liquid by Archimedes Principle
6	Determination of density of a wooden black using beam balance and vernier scale
7	Determination of the density of a floating body (wooden block)
8	Determination of density of the material of a body without using any standard weight
9	Concept of gravity and determination
10	To study moment of inertia with lamina
11	Use of friction table for studying friction
12	To study amplitude decay & energy dissipation with a simple pendulum
13	To study extension of a spring & its calibration for using it as a spring balance
14	To study oscillation of a single spring, two springs in series & two in parallel
15	Demonstration of the validity of law of parallelogram of force.
16	To study stationary waves on a string and hence verification of the laws of vibration of string using a speaking and a step-down transformer
17	To study resonance of sound in a tube with a speaker & an audio oscillator
18	Hydrostatic balance in a U tube and measurement of density of a liquid
19	A study on the Hydrodynamics of a water jet
20	To determine surface tension of water using capillary tube
21	To determine young modulus of copper using long wire
22	Convergence property of a convex lens & determination of its focal length using a filament
23	Determination of focal length: displacement method
24	Determination of the focal point of a concave lens in combination with convex lens.
25	Experiments based on the principle of rectilinear propagation of light
26	Verification of inverse square lens in photometry. Determination of the refractive index of water using a) a concave mirror b) a plane mirror and a convex lens
27	Determination of the refractive index of water using i) a concave mirror, ii) a plane mirror and a convex lens
28	Determination of the focal length of a convex mirror using a convex lens of known focal length
29	To prepare a telescope with two convex lenses
30	To study spherical aberration and chromatic aberration in a lens
31	Determination of acceleration due to gravity by simple pendulum
32	Verification of laws of reflection using plane mirror
33	Determination of the rotation of the reflected ray when the mirror rotates through an angle
34	Verification of laws of refraction of light using glass slab/glass prism
35	Preparation of hallow prism and determination of minimum deviation of light ray and hence the refractive index of liquid/solution, its variation with concentration and temperature
36	To study diffraction of light through i) a single slit, ii) a double-slit and iii) a multiple-slit using laser torch

Continuation of the table

37	To determine the magnetic moment of a magnet using three ring magnets and a hallow plastic pipe through the magnets can play
38	To determine the horizontal component of earth's magnetic field using a ring magnet and of known magnetic moment
39	To determine Curies temperature of a ferrite rod
40	To use electrical meters such as analogue galvanometer, voltmeter, digital Multi-meter's etc
41	To study the validity and limitation of Ohm's Law using i) carbon resister, ii) torch bulb, iii) thermostat, iv) LDR, v) rectifying diode, v) Zanier diode, vii) LED
42	To study the series and parallel combination of resistors.
43	Preparation of thermocouple and its use to measure temperature
44	Determination of meting point of wax
45	Determination of latent heat of melting ice and vaporisation of water
46	To study Newton's Law of Cooling
47	To determine specific heat of solid & liquid studying cooling curve
48	To construct a potentiometer and use it in measuring voltage and current in a circuit, and electromotive force of a source, as a voltage divider
49	Construct and use a meter bridge
50	To find the resistance and sensitivity (figure of metre) of a galvanometer
51	To find the resistance of a voltmeter
52	To convert a galvanometer into i) a millimetre and ii) a voltmeter
53	To study mutual inductance between two coils
54	To determine the frequency, rms and peak voltage of an AC source
55	To study CR circuit with DC
56	To study CR with AC
57	To study LCR circuit with AC
58	To study LCR circuit with DC
59	To construct phasor diagrams
60	To study the characteristics of a step-down transformer
61	To construct AND, OR and NOT gates from basic circuit elements
62	To determine Plank's constant with LED

Appendix 5

The manual for the physics laboratory at Anveshika-Kanpur

S. No.	**Title of the demonstration/experiment**	**Domain**	**No. of copies**
1.	Charge balloons and see their attraction and repulsion	EM	1
2	Example of force equation with a charged balloon	EM	3
3	More lessons from charged balloon	EM	3
4	Deviation of water stream by balloon	EM	1
5	Magnetise a needle in one stroke	EM	1
6	Which is good conductor and which is poor conductor	EM	1
7	Make your electroscope and study charging by rubbing	EM	1
8	Series and parallel combination of resistances	EM	2
9	Practice with W=i2R	EM	2
10	A magnet falling through a conducting tube	EM	3
11	Jumping ring	EM	3
12	Hanging ring	EM	3
13	Eddy current brake	EM	3

Continuation of the table

14	Eddy current accelerator	EM	3
15	Magnet following rotating disk	EM	3
16	Motion of charged particle in magnetic field	EM	3
17	Magnetic shielding	EM	3
18	To make an electromagnetic swing	EM	3
19	See waves on water surface and measure AC line frequency	EM	3
20	Magnetic field by changing Electric field	EM	4
21	Change in voltmeter reading as the side is switched	EM	4
22	Faraday's law of EM induction from current detector	EM	2/3
23	Current detector	EM	2/3
24	Faraday's law of EM induction from current detector	EM	23
25	Snake's head	EM	23
26	Resistance of a bulb head	EM	23
27	Electric motor, safety pin	EM	23
28	Electric motor, Ashok Bhagat	EM	23
29	Electric motor, Mukesh	EM	23
30	Magnet with unequal pole strength	EM	2
31	Attraction repulsion between straws (P. Suryanarayan, Chennai)	EM	1
32	Pop up AL foil	EM	3
33	Paper Speaker	EM	3
34	Oerested Experiment	EM	3
35	Magnetic lines of force	EM	23
36	Faraday's laws (G, Magnet, different numbers of turns)	EM	
37	Check the conductor	EM	3
38	Mother Coil Glow bulb at different height	EM	2
39	Vanishing of coin with match box	Games	3
40	Burst small and large balloon	Games	0
41	Throw spinning partially filled bottle	Games	0
42	Brahma Vishnu Mahesh Disk	Games	2
43	Prove that there is air in the bottle	Games	1
44	Air pressure from Pichkoo bottle	Games	1
45	Read on flickering name plate	Games	1
46	Burning candles in limited air	Heat	1
47	The cap comes out on heating	Heat	1
48	See convection current in air	Heat	1
49	Study the role of air in burning candles	Heat	1
50	Calorimetry in drinking glass	Heat	2
51	Get latent heat of fusion of ice	Heat	2
52	The drinking duck-1	Heat	2
53	Why does water rise in the burning candle experiments?	Heat	
54	The drinking duck-2	Heat	3
55	The drinking duck-3	Heat	3
56	Partially filled inverted glass	Heat	3
57	Boiling water with cooling it	Heat	12
58	Compare thermal conductivities of two metals	Heat	23
59	Dew point	Heat	23
60	Sikka kare takk	Heat	2
61	Warm water is lighter than cold	Heat	2
62	All out therma-meter	Heat	3

Continuation of the table

63	Boil water in paper glass	Heat	2
64	Heat balloon filled with water	Heat	2
65	Expand wire by passing current	Heat	2
66	Measure temperature with thermocouple	Heat	3
67	One marble appears two	Illusion	1
68	T shape with two straw pipe	Illusion	1
69	Which one is bigger curve	Illusion	1
70	Hole in palm	Illusion	1
71	Drop coin in beaker	Illusion	1
72	Close an eye and match the nail head	Illusion	1
73	Contraction of a plastic bottle having stream, air pressure	Mechanics	1
74	Why does it go up	Mechanics	1
75	Motion of Sun-Earth-Moon	Mechanics	1
76	Newton's third law (two students pulling each other)	Mechanics	1
77	Know your reaction time using plastic scale		2
78	Order obeying bottle, air pressure		2
79	Check Newton's 3rd law		2
80	Light the ball by oscillating it		2
81	Time period and length of pendulum		23
82	Rolling friction is smaller than kinetic friction		2
83	Liquid attains same height		2
84	Measure the angular speed of a motor		2
85	Make a very slow floater		2
86	Syphon glass		2
87	Ganeshji drinking milk		2
88	Find the breaking tension of a thread		2
89	Discover the force law		3
90	Get familiar with springs and spring constants		3
91	Check the validity of time period of spring-mass oscillation		3
92	Resonance on plastic drop		3
93	Get terminal velocity of a water drop		3
94	Blow air in a polythene bag		3
95	Lift a weight by moving another weight in a circle		3
96	Show Conservation of angular momentum		3
97	Who rolls fast?		3
98	Centripetal Separator		3
99	See surface tension at work-1 (pushing pepper)		3
100	See surface tension at work-2 (floating blade)		3
101	Separate glass slides stuck with water		3
102	Chit-Chit magnet angular momentum		3
103	A vertical force causing motion in horizontal direction		3
104	Goes forward, goes backward		3
105	See surface tension at work-3 (soap film)		3
106	Resonance I pendulum by hand		3
107	Surface tension balance, Awasthi Agra		3
108	Gyroscope from cycle wheel		3
109	Ladder problem friction		3
110	Water projectiles from different holes in a bottle		3
111	Key-bottle experiment		3

Continuation of the table

112	Measuring coefficient of restitute between balls and floor		3
113	V top=2 v centre in rolling motion		3
114	Effect on apparent weight as a person accelerates		3
115	Study the phase difference between two SHMs		3
116	Collision experiments Carom board		3
117	Velocity of waves in on slinky		3
118	Effect of mass density of a medium on the waves speed is it		3
119	Find the value of g using an inclined plane		3
120	Find moment of inertia of an inclined ring and g		3
121	To learn about friction from a coin experiment		12
122	Torque balance of Joshiji		12
123	Study of Atmospheric Pressure using Syringe		23
124	How much is 1 Newton		23
125	Weightlessness in free fall		23
126	Find friction Coefficient		23
127	Where is the centre of mass		23
128	To measure the force of buoyancy		23
129	Will the water flow		23
130	Why does not water flow		23
131	Spring in a series		23
132	Springs in parallel		23
133	Weithlessness-2		23
134	Falling paper in vacuum		23
135	Person sitting on chair		23
136	Man against the wall		23
137	Torsional waves on straws		23
138	Nail balance		1
139	Balancing question mark plate		2
140	Hold the pipe from a circular cross-section Periphery		2
141	Feel the Pressure from Bricks		1
142	Spinning bottles		23
143	Ziddi Sikka, Friction		12
144	Pull paper below a load		12
145	Pull paper from between bottle cap and coin		12
146	Weight a scale with 1g weight		2
147	Find the inner diameter of refill		2
149	Find ‘g’ from oscillation of physical pendulum		2
149	Determine size of hole to allow water falling		2
150	Bring the coin up in match box		3
151	Antigravity test tube		2
152	Water comes out if you drop the shop solution		3
153	Chota blower		3
154	Vacuum cleaner		23
155	Magical ball		1
156	Who will drink first		2
157	Rocket principle		2
158	Water flow with the help of thread		2
159	Balancing CG (Plastic Pipe with ball)		23
160	Babua		2
161	CD Balancing by clip and coin balancing with fork		2

Continuation of the table

162	Copy works like a magnet		23
163	Inflate the balloon in a syringe		2
164	Make friendship between two film can		3
165	Hang the plastic glass		3
166	Blow the balloon in flask		2
167	Blow the paper ball		2
168	Pichku Bhoppu		2
169	Dhar Bedhar		1
170	PVC Hand pipe		2
171	Which bottle will become empty first		3
172	Water level is always same		1
173	Manometer		2
174	Concept of density		2
175	Prove Archimedes law Plastic Glass		3
176	Where is pressure more in balloon		3
177	Know your reaction time using table clock		3
178	Blow above paper strip		23
189	Burst balloons on Nail bed		2
180	Archimedes Divers		3
181	Break the thread , upper and lower		3
182	Coupled pendulum on thread		4
183	Lift the paper covered with paper		23
184	Look at the colours of white light	Optics	2
186	Optical fibre action in parabolic water stream		2
186	Refractive index by lateral displacement		2
187	Refractive index by parallax		2
188	To study the laws of reflection of light		2
189	Scattering of blue light		2
190	Optics with light ray box		2
191	View single slit diffraction pattern		3
192	Look at the diffraction pattern from the wire/hair		3
193	Measure the thickness of hair		3
194	Multiple reflection from a slab		3
195	Polarisation by reflection from water		3
196	Measuring the critical angle for water-air interface		3
197	Study of path of light when it encounters a prism		3
198	Get the focal length of a concave mirror		3
199	Pass laser light through polariser and rotate		3
200	To see the Poisson's point		4
201	Make your optical bench		23
202	Total internal reflection in Dettol bottle		23
203	Every student owns a prism		23
204	Underwater optics		23
205	Make convex and concave lens from the same bottle		23
206	See dispersion of light by a prism		23
207	Reflection in smoky plastic box		12
208	Make six torch by torch		3
209	Why does empty beaker shine		3
210	Periscope		2
211	Focal length of a convex lens		23
212	Convex lens behave as a concave lens		23

Continuation of the table

213	Converging, diverging and straight ray of light		2
214	Light travels in a straight line		12
215	Lots of images between two plane mirror		3
216	Play with convex lens sliding box		23
217	Coin vanishes below water filled beaker		3
218	Make standing waves on a string	Waves	3
219	Make standing waves on a string using an oscillator		3
220	Study the laws of standing waves on a string		3
221	Beats with convex lens and bulb		3
222	Thali waves		3
223	Resonance by hand pendulum		2
224	Torsional waves on straws		3
225	Sound in water pipe (Siron)		2
226	Sound in Straw		12
227	Sound in partially filled glass		1
328	Waves on membrane using laser torch		2
229	Crazy ball comes back to you	Mech	13
230	Magnet falling through spoke	EM	1
231	Wheatstone Bridge with bulbs		3
232	Mobile EM pick up		4
233	FM Radio Mutual Inductance		3
234	Capacitor time constant		3
235	Chromatic Aberration	Optics	2

Appendix 6

'Manual of Low-Cost Laser Experiments' by Ved Ratna and K. C. Thakur (2003)

S. No.	Demonstration Experiment
1	Light travels in straight line
2	Looking inside a milky electric lamp
3	Shadow formation by a point source of light
4	Shadow formation by an extended sources of light
5	Reflection by a plane mirror
6	Reflected ray rotates twice the rotation of the mirror
7	Refraction in water
8	(i)Refraction in a glass slab (ii)Partial reflection from the surface of a glass slab (iii)Total internal reflection in a glass slab
9	Multiple reflection in a mirror
10	Reflection of parallel rays by plane mirror
11	Reflection of parallel rays by concave mirror
12	Reflection of parallel rays by convex lens
13	Refraction of parallel rays by convex lens
14	Refraction of parallel rays by concave lens
15	Demonstration of correction of Myopia
16	Demonstration of correction of Hypermetropia
17	Effect of medium on focal length
18	Real images made by a convex lens
19	Real images made by a concave mirror
20	Deviation of a rays of light by a prism

Continuation of the table

21	Lens is an aggregate of many tiny prisms
22	Any rectangular glass slab is really a prism of small angle (study by deviation of rays of light)
23	Total internal reflection in 45^o
24	Total internal reflection in a water cube
25	Multiple total internal reflection in shallow milky water
26	Experiments by 45^o prism
27	Total internal reflection in optical fibre
28	Observing pure spectrum of torch bulb
29	Projecting bright pure spectrum of 60W/100W lamp, by a prism
30	Focal length for red no longer than that for blue for a convex lens
31	Colours of objects
32	Diffraction pattern made by a single slit
33	Interference pattern made by a double slit
34	Polarisation of light by polaroids
35	Polarisation of light by reflection
36	Reflection of diode laser beam by a shining surface
37	At Brewster's angle of incidence, reflected ray is perpendicular to refracted ray
38	Polarisation of light by scattering
39	Optical rotation of plane polarised light by sugar solution
40	Projecting pure spectrum of 60W/100W electric lamp by diffraction grating
41	Observing solar spectrum and Fraunhoffer lines by low cost spectroscope
42	Diffraction by a thin wire/human hair
43	Diffraction by ultra-thin fibre of circular cross section
44	Diffraction by thick wire and wide slit
45	Diffraction by a grid of circular holes and a single circular hole
46	Diffraction by a grid of circular discs and a single circular disc
47	In total internal reflection, electric field of a light beam goes beyond geometrical boundary of denser medium (by using laser)
48	In total internal reflection, electric field of a light beam goes beyond geometrical boundary of denser medium (without laser)
49	Twinkling of a star is fluctuation of light flux entering our eyes (demonstration by a diode laser)
50	Observing twinkling of a star by a telescope, to show that it is light flux fluctuation
51	Is a polariser a perfect polariser? Is a diode laser beam perfectly plane polarised?
52	The rectangular glass slab is really a prism of small angel (study by partial reflection)
53	Temporal coherence of laser light beam
54	Is the laser beam a parallel beam of light
55	Optical fibre of water
56	Focal length of combination of two lenses
57	Blue scatters more than red by fine particles
58	Demonstrating TIRAT Glass-water interface by laser

Appendix 7

Low-Cost Laser Based Demonstration Experiments in Optics by Ved Ratna (2006)

S. No.	Title of Experiment
1	Precision study of law of reflection
2	Variation of intensity of partially reflected beam
3	Investigating law of refraction by a rectangular glass slab
4	Investigating law of refraction by a semi-circular glass slab
5	While going from denser to rarer medium, ray of light bends away from normal 9study by laser and semi-circular glass slab)
6	Total internal reflection in a semi-circular glass slab and refractive index of glass
7	Total internal reflection from water to air by air cell
8	Focal length of a convex lens of long focal length
9	Focal length of a concave lens of long focal length
10	Study of relation between u and v and magnification of image, using a filament lamp and convex lens
11	Study of deviation of white light and its dispersion by a 60 degree prism
12	Focal length of a convex lens for yellow and difference of focal lengths for red and violet
13	Making a simple astronomical telescope and to find its magnifying power
14	Finding “advantage in seeing fine-details” by a telescope. Is it same as magnifying power?
15	Focal length of single element telescope objective for violet, red and yellow

Appendix 8

Manual of Low-Cost Laser Experiments by Ved Ratna and K. C. Thakur (2006)

S. No.	Title of Experiment
	(A)Lens as a collection of tiny prisms
A1	To study the behaviour of a lens as a collection of tiny prisms and thus measure the focal length of a lens of long focal length within a space less the 1 metre 9double convex lens)…………same experiments with concave-convex lens
A2	To study the behaviour of a lens as a collection of tiny prisms, by graphical method
A3	To investigate spherical aberration of a lens
A4	Chromatic aberration of a converging lens
	(B)Displacement of a ray of light by a rectangular glass slab
B1	To study the relation between displacement produced by a rectangular glass slab in a ray of light and angle of incidence of the ray and thus find refractive index of its material
B2	To study precisely the relation between displacements produced by a glass slab in a ray of light and angle of incidence of the ray, around $i = 45^\circ$.
B3	To study the relation between displacement produced by a glass slab in a ray of light and angle of incidence, thus find precisely the refractive index of slab
B4	Making spectrum by a parallel sided glass slab
B5	To study the relation between angle of incidence and angle of refraction in a glass slab, by the help of displacement it produces
	--
	(C)Total internal reflection and minimum deviation in a prism

Continuation of the table

C1	To study the total internal reflection of a ray of light in a glass prism and thus find its refractive index T.I.R. in a hollow glass prism filled with a liquid
C2	To study the minimum deviation of a ray of light by a prism and thus find refractive index of material Repeat the experiment by using a hallow glass prism filled with liquid
C3	To study the relation between angle of incidence and deviation produced by a prism and thus find refractive index of material of the prism
C4	Precise measurement of refractive index by minimum deviation, without measuring angle of prism
C5	Refractive index of a liquid by T.F.R. at glass liquid interface in a glass prism
	--
	(D) Diffraction by a single slit
D1	To study the diffraction pattern produced by single slit and find wavelength of the light of a diode laser
D2	To study the diffraction pattern of a single slit by graphical method
D3	To study the diffraction pattern of a single slit by optical method
D4	To study the relation between (i) fringe width and slit width and 9ii) fringe width and distance of screen, in the diffraction pattern of a single slit. Improvising a parallel slit of razor blades
	--
	(E) Interference by double slit
E1	To study the interference pattern produced by a double slit and find wavelength of diode laser light
E2	To study the interference pattern produced by a double slit, without suing an optical bench
E3	To study the relation between (i) fringe width-x and slits separation-d and (ii) fringe width-x and distance of screen-D in the interference pattern of a double slit Improvising a slide of double slits with various separations
E4	Ratio of wavelengths of diode lasers No. 1 and 2, by interference fringes
	(F) Polarisation: Measurement of Brewster's angle
F1	To study the reflection of plane polarised light at a polished surface and thus measure Brewster's angle and refractive index for glass/acrylic/granite/Sun-mica
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	(G) Optical Rotation
G1	To study the relation between angle of optical rotation produced in a ray of plane polarised light by a column of sugar solution and its concentration, using a: demonstration polarimeter".
G2	To study the relation between angle of optical rotation produced in a ray of plane polarised light by a column of sugar solution and its length
G3	To find the specific rotation of sugar
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	(H) Diffraction by a straight edge, thick rod and wide slit
H1	To observe and record the diffraction pattern produced by a straight edge, thick rod and white slit
	--
	(J) Diffraction by a thin wire
J1	To study the diffraction pattern of a thin wire by a laser of known wavelength and find its diameter
J2	To study the diffraction pattern of an ultra-thin nylon fibre and find its diameter Simple explanation for extra pair of dark fringes

Continuation of the table

J3	To investigate the rule which determines positions of dark fringes in the diffraction pattern of an ultra0thin nylon fibre with circular cross section Theoretical explanation of the rule fro diffraction by a thin wire.
J4	To investigate how much does the cross section of a thin wire/ultra0thin nylon fibre deviate from circular shape
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	(K) Diffraction by a tapered slit
K1	To study the relation between width of central fringes and slit width in the diffraction pattern of a tapered slit
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	(L) Diffraction by circular hole
L1	To study the diffraction pattern of a square grid of holes and thus find the grid spacing and diameter of holes, by using a laser of known wavelength
L2	Above experiment for a square grid of black circular discs.
L3	Diffraction pattern of lycopodium seeds spread on a glass plate
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	(M) Interference by a diffraction grating
M1	To measure the line spacing of diffraction grating using a laser of known wavelength
M 2	To measure the wavelength of light of diode laser B with the help of a laser A of known wavelength (HE-Ne laser of 632.8 nm or a standardised diode laser