Chapter 1

Introduction

The present research explores, how utilizing Physics Education Research (PER) strategies may lead to the enhancement in conceptual understanding of fundamental concepts of Solid State Physics, amongst students studying the subject at Undergraduate (UG) level and Postgraduate (PG) level. The same can be applicable for students studying Solid State Chemistry at Senior Secondary level. The extent of enhancement has been measured with the help of scores obtained on the concept inventory which is another Physics Education Research tool.

In this interdisciplinary study, the researcher has included the research designs/strategies from both disciplines i.e. Physics and Education. The major tasks accomplished through the study include preparing a Concept Inventory (CI), devising Expected Learning Outcomes (ELOs) and Intervention Modules (IMs) and assessing the effectiveness of the Modules through the Concept Inventory.

1.1 Physics Education Research (PER) : Definition

Physics Education Research has been defined in various texts in the following manner
Physics education or physics education research (PER) refers both to the methods currently used to teach physics and to an area of pedagogical research that seeks to improve those methods.\(^1\)

Physics education research provides a framework for investigating physics education and shaping effective educational practice. \(^2\)

The mission of Physics Education Research is to provide an empirically tested theoretical framework to help build the science of teaching-learning of physics with rigor characteristic of research in pure sciences. \(^3\)

Physics Education Research (PER) is research into the learning, understanding and teaching of physics and the application of physics knowledge\(^4\).

Thus, as per the nomenclature and various texts referred above, PER refers to employing the techniques of education research not only to investigate the various processes associated with the pedagogy of Physics but also to gauge the shortcomings and suggest as well as develop measures to overcome these shortcomings.

1.1.1 History and Origin

The field of Physics Education Research originated as a result of detecting college-level students’ difficulties in understanding the primary concepts of Physics. This initiative was taken up by Lillian McDermott, while she was an instructor (hired by Arnold Arons) for courses with teacher education. The same issue was extended to pre-college level by Bob Karplus. Afterwards, many Physics Education Research groups emerged, with the purpose of not only identifying the difficulties associated with understanding the ideas in Physics, but also to devise remedial educational and instructional reforms for addressing these difficulties\(^5\). Physics Education, thus, slowly and steadily branched out not only as an authorized subfield of Physics, but in the words of Edward F. Redish (another First Generation PE Researcher) started being considered as “harder than nuclear physics and rocket
1.1.2 Sub-fields Within PER

The research associated with the monitoring of how students learn Physics, has been named as Basic PER. Applying and utilizing the findings of Basic PER to design and develop instructional reforms for dealing with the issues identified, has been named as Applied PER. Both Applied and Basic PER lead the path for improving the pedagogy of Physics[^5]. The various aspects of PER have been classified under Basic and Applied PER. The Basic PER aspects include Behavior, Achievement, Teacher & Student Characteristics, Cognition etc., while those under Applied PER are Pedagogy, Curriculum Development, Instructional Material Design etc.

The present research is a combination of both Basic and Applied PER. It includes identification of alternative Conceptions, Revised Bloom’s Taxonomy for developing the Concept Inventory and Expected Learning Outcomes and Guided Inquiry Strategy and Activity Based Learning as foundation for designing Intervention Modules for teachers and students. Furthermore, the effectiveness of the Modules was assessed using the CI.

1.1.3 The Concept Inventory

Considered as a major landmark in the history of PER is the development of Force Concept Inventory by Hestenes et al.[^9] and its administration on almost 6000 Physics studying students, by Richard Hake[^10]. The concept inventory or questionnaire comprising of Multiple Choice Questions, was based on fundamental concepts of Newtonian Mechanics and was a result of extensive research done on this topic by Ibrahim Halloun[^11]. The results obtained by Hake revealed that students studying Mechanics through interactive engagement methods, outperformed those studying through traditional method. Hence the need and importance of educational and instructional reforms got highlighted and PE Researchers ex-
tended their work in different branches of Physics. Since then, students’ difficulties in many areas of Physics have been identified, various surveys have been conducted in order to probe about students’ expectations from a Physics based course, many concept inventories have been developed and administered and findings have been reported\cite{12}. Technology based educational reforms (which include Modeling and Simulation) have also found their way through PER\cite{13}. In this manner, PER became a full fledged research area where a lot has been discovered and a lot more remains to be discovered. The main task of PER thus remains what is the main task of teaching, to make Physics students (Novice) think, understand and comprehend Physics like Physics instructors (experts).

1.2 Review of the Literature Related to the Study

This section will comprise of a review of the work done in the field of PER which is associated with the present study.

1.2.1 Physics Education Research

The section includes the review of the articles which lay a foundation for the Researcher in the field of PER.

Beichner\cite{5} has given a brief introduction of the field of PER starting from the roots of its origin in United States to the currently persisting research traditions in the field. The author emphasizes that PER is definitely not the process of Physics Education/curriculum development.

McDermott & Redish\cite{12} have given a compiled report of the work done in the various subfields of PER. The article has not only tried to cover the various associated branches of PER, but has also listed almost all the relevant literature available in this context.

Redish & Wittmann\cite{14} have recommended to expand the PER arena in the light of
five major categories in order to make PER a more scientific field. The authors have raised twenty epistemological and ontological questions associated with the following fields:

- the model of the participants
- the model of the context
- the model of the content
- the engineering of instruction
- the overall epistemology of PER — How do we decide when we think we know something?

The aim of this paper is to extend the focus of PER from improving the instructional methodologies to understand the pedagogy of Physics.

Docktor & Mestre [15] have presented an extensive description of PER done at the Undergraduate level. The collected work has been classified under the categories namely

1. assessment,
2. cognitive psychology,
3. attitudes and beliefs about teaching and learning,
4. conceptual understanding,
5. problem solving, and
6. curriculum and instruction.

For each category, research questions, theoretical frameworks, associated research methodologies, key findings, strengths and limitations of the research and area of future study has been discussed. Thus this paper gives in great detail what all has been done in context of PER at Undergraduate level.

Redish [10] has proposed a theoretical framework for PER. This has been done
through an amalgamation of various disciplines which include Neuroscience, Education, Sociolinguistics and Physics. The author has attempted to not only analyse the cognitive level of the individual but also its interaction with the surroundings while Learning of Physics takes place. The author has also recommended certain models for student thinking and learning.

Wieman & Perkins [17] have emphasised that it is important not only to guide students while studying Physics but to transform their thinking from that of a novice to that of an expert through various means which may include simulations or any other research based strategy.

Harrisona [18] has discussed the various reasons which might be cited by him as well as by the faculty of Physics for not implementing and incorporating the results and Educational implications of PER. The author eventually adopted PER instructional methodology and shared his experience and feedback after the transformation.

1.2.2 Misconceptions/Preconceptions/Alternative Conceptions and Concept Inventory

1.2.2.1 Identifying Misconceptions

Clement [19] has identified strong alternative conceptions amongst students which focus the relationship between force and acceleration through written tests and video-taped interviews. Author has compared these conceptions with those of the Galileo. Galileo’s writings have been cited and conceptions amongst students have been discussed in the light of his views. It has been recommended that these conceptions either need to be molded or to be replaced by correct conceptions.

Mountcastle et al. [20] have identified preconceptions related to probability and uncertainty. It has been mentioned that unlike the assumptions of textbooks students are unable
to deduce about the uncertainties associated with the outcome of binary events though they were almost right in predicting the probability for the same.

Zhu & Singh [21] have identified difficulties amongst undergraduate and graduate students related to quantum measurements. The authors have employed surveys as well as interviews for to probe the origin of these difficulties amongst the students. The results have been comprehended and analysed for preparing research based educational reforms for teaching the concept.

Prescott & Mitchelmore [22] have identified the misconceptions associated with Projectile Motion amongst Year 12 Australian mathematics students. The students’ Mathematical treatment to the concept has been found to be based on a variety of Aristotelean, impetus and Newtonian conceptions rather than just Newtonian Framework. Also discussed are the educational implications for teaching projectile motion.

Berman [23] has identified 15 misconceptions based on cosmology, relativity and gravitation and also suggested suitable corrections.

1.2.2.2 Devising Concept Inventory

Adams & Wieman [24] have outlined the process of developing and validating the assessment test which measures the effectiveness of a given instructional strategy. The importance of interviews for creating the assessment test has been emphasised. Methods for administering the test effectively have been discussed. The following crucial steps have been prescribed in the paper

1. Important topics from the point of view of teachers, college or university faculty members have to be identified.
2. Interviews and observations should lead to identify student thinking related to these topics and the how it is different from expert thinking.
3. Tests, based on open-ended questions, have to be administered for probing student thinking pattern.

4. For measuring student thinking, a forced answer test has to be created.

5. Validation interviews has to be conducted, on the test questions, with both novices and subject experts.

6. Finally, the forced answer test has to be administered to classes and the results are to be analysed through statistical tests.

These steps form a strong basis for conducting PER.

Richardson [25] has also listed the steps involved in the preparation of a concept inventory. The author has emphasized how concept inventories are effective tools for revealing the thought process of the students of Science, Engineering, Technology and Mathematics, regarding a particular concept. They can thus prove to be, quite helpful for improving the educational strategies.

Hestenes et al. [9] have devised Force Concept Inventory, a breakthrough in PER and an assessment instrument, based on ‘force’ which is the fundamental idea of Newtonian Mechanics. The purpose of designing FCI was to explore students’ common sense beliefs on force and how these beliefs align with the Newtonian Concept of ‘force’. The authors have discussed the process of its designing, its usage and the results yielded by administering it on various students studying Physics in different courses of Physics. It was discovered that FCI has been an effective tool in assessing about the instructional strategies being employed by Physics Instructors.

Savinainen & Scott [26] have utilised FCI, to judge the effectiveness of a research based educational reform, devised to teach mechanics at Upper Secondary School.
McKagan et al. \cite{27} have discussed the designing and validation process of Quantum Mechanics Conceptual Survey (QMCS), an effective assessment tool for evaluating Instructional methods in Modern Physics. The survey contains 12 questions and the whole process of designing and validating the survey, which included observations of students, a review of previous literature and textbooks and syllabi, faculty and student interviews, and statistical analysis, has been discussed. The utility of the survey has been recommended in various contexts.

1.2.3 Educational/Instructional Reforms

Based on the identified misconceptions, one can develop the ELOs and effective instructional strategies can be devised accordingly. The various educational reforms have been discussed in the light of various subjects associated with Physics.

1.2.3.1 Comprehensive List of Educational Reforms

De et al. \cite{28} have proposed to use spreadsheet as an interactive learning environment creating tool in Physics. The various contexts in which the spreadsheet can be used for this purpose are Electrical circuits, external and internal reflections using Fresnel equations, diffraction pattern due to 4 slit, airy pattern and diffraction due to rectangular aperture.

Henderson & Dancy \cite{29} have explored about the knowledge and application of Research Based Instructional Strategies of Introductory Quantitative Physics, amongst 722 Physics faculty across United States.

Krusberg \cite{30} has discussed three emerging technological tools namely Physlet Physics, the Andes Intelligent Tutoring System (ITS), and Microcomputer-Based Laboratory (MBL) Tools. These have been analyzed for their effectiveness in bringing conceptual change, developing expert-like problem-solving skills, and achieving the goals of the traditional physics laboratory. Pedagogical methods to maximize the utility of each educational
Loverude has developed questions for probing the understanding of probability. Many students were found to have difficulty not only in differentiating between microstate and macrostate and but also in the application of the concept of multiplicity to simple systems. The author has devised a tutorial to address these difficulties. Results of preliminary administration of the tutorial has been shown and modifications needed based on the results, have been discussed.

Kelly et al. have employed 5E pedagogy (based on Engage, Explore, Explain, Expand and Evaluate), along with Just-in-time teaching and Clicker questions, to build conceptual modules for teaching Material Science. These modules included worksheets, sample data tables, controlling equations, illustrations and graphical relationships. A Materials Concept Inventory and two tiered questions have been also developed to assess the effectiveness of the modules.

Vigeant et al. have devised a pair of inquiry-based activities for each of the five concepts of Thermodynamics. Performing the activities involved, making predictions (derived from the misconceptions) and analysing the results obtained which need conceptual understanding and thus remove the misconceptions.

Prince et al. have discussed the development and testing of both concept inventories and inquiry-based activities to identify and deal with the students’ misconceptions regarding engineering Heat and Thermodynamics.

Nakamura et al. have developed three lessons on Newton’s Laws and implemented them on the Internet. The authors have done both qualitative as well as quantitative analysis of the results obtained through these lessons.

Smith et al. have devised guided inquiry conceptual worksheet (or tutorial) for
teaching the concepts of Carnot’s efficiency and the Carnot cycle and have found that students’ understanding improved as a result of implementing these worksheets.

Zhu & Singh[37] have devised and proposed to use Quantum Interactive Learning Tutorials (QuILTs) along with Peer Instruction in order to minimize students’ difficulties associated with measurement in Quantum Mechanics. The authors[38] have also suggested to employ QuILTs in order to aid students of Advanced Undergraduate and Graduate courses, who have difficulties in addition of Angular Momentum.

Tobochnik & Gould[39] have recommended illustrating fundamental concepts in Statistical and Thermal Physics by considering various models and algorithms.

Tobochnik et al.[40] have also advocated to utilize the Monte Carlo algorithms and applications in order to understand the concepts of Temperature and Chemical Potential.

Wittmann et al.[41] have prescribed a set of activities to teach Probability and Probability Density and have mapped students’ thinking pattern apart from analysing Pre-test and Post-test results.

Identifying Misconceptions, designing Concept Inventory and devising suitable educational interventions, all are crucial aspects of Physics Education Research. These have been discussed, in context of the present research, in greater detail, in the subsequent chapters of the thesis.

1.3 Rationale for the Research

Quite a lot has been done through PER in various courses associated with Physics. These include[12]

• Light and Optics
• Modern Physics
• Properties of matter, Fluid Mechanics and Thermal Physics
• Electricity and Magnetism
• Mechanics

Solid State Physics still remains an unexplored field in this regard. Though Sharma et al. have devised instructional/learning objectives for Solid State Physics based on the Undergraduate curriculum of the subject prescribed in B.Sc. (Honors and Pass Course) in Physics of Himachal Pradesh University, India, and few initiatives have been taken to refer to several concepts (details given in Chapter 3), any attempt of identifying students’ conceptions (misconceptions or preconceptions or alternative conceptions) has yet to find its way through PER.

Solid State Physics or Condensed Matter Physics is the study of behaviour of atoms and molecules in solid or condensed form of matter and also of associated phenomena. The traditional method of teaching employs students being taught about various crystal structures and crystal lattices using one or two dimensional methods of teaching which may include board or power point. But considering the involvement of three dimensional entities, the traditional method of teaching may not be able to make students visualize the structures and lattices in their original form. Thus, PER in Solid State Physics will not only target to bring about improvement at the cognitive level but also to enhance and magnify the visualisation ability of the students.

As a result, there arises a need to adopt and implement PER for Solid State Physics. There are many other reasons for selecting Solid State Physics, the foremost being that the subject involves cognitive, visualisation and Mathematical ability because of which it is considered as one of the most difficult subject by the students. Researcher’s personal experience regarding the teaching and learning of the subject at her undergraduate and post graduate
level and her interest in the subject has also led to the decision of making Solid State Physics as the focal point of this study. It is also to be considered that most of the times, the teaching about three dimensional identities, takes place by either using one or two dimensional strategies (board, power points etc.). This might not be able to deal with the problem of lack of visualisation in this subject.

1.4 Research Questions

The following research questions will be addressed during the course of the present study:

1. What is the present status of conceptual knowledge of the fundamental concepts of Solid State Physics amongst the students studying the subject at the Undergraduate level and Postgraduate level?

2. How do various PER strategies contribute towards the attainment of enhanced conceptual understanding of chosen concepts of Solid State Physics amongst the students studying the subject at the Undergraduate level and Postgraduate level?

3. To what extent does the conceptual understanding about the chosen fundamental concepts of Solid State Physics gets enhanced amongst the students studying the subject at the Undergraduate level and Postgraduate level?

1.5 Objectives of the Study

The objectives of the present study are as follows:

1. To probe the preconceptions amongst students, in order to ascertain the present level of conceptual understanding regarding the various elementary topics of Solid State Physics
2. To formulate the appropriate activities and design expected learning outcomes as well as Intervention Modules for the teaching of the basic concepts associated with Crystal structure

3. To develop a concept inventory of foundational topics of Solid State Physics, based on the identified misconceptions/alternative conceptions/preconceptions

4. To test the effectiveness of the Intervention Modules, using the designed concept inventory, in enhancing students’ knowledge of these concepts.

5. To formulate an activity for arriving at the 3-D Bravais Lattices using 2-D Bravais Lattices

6. To propose Simulation based activities for arriving at the 3-D Crystal Structure of an element and for determining its Cohesive Energy

1.6 The Strategies

As mentioned before, the present research takes into account, the aspects of both Physics and Education disciplines. Discussed here are the strategies employed from these.

1.6.1 Activity Based Learning

Chickering & Gamson have identified seven principles of good education at UG level and utilizing active learning techniques blended with structured exercises, is one of them. Jonassen & Churchill have also emphasized that meaningful learning is an outcome of engaging activity. Khan et al. and Hussain et al. have studied the effect of Activity-Based teaching and Peer Group activity based learning on Secondary School students studying Physics. In both the cases the academic achievement of the students was found to have improved significantly. That is why, activity based learning form a strong basis for the Intervention Modules to be developed in the present research, in order to teach the fundamental concepts of Solid State Physics.
1.6.2 A Constructivist Approach to Teach Solid State Physics: Guided Inquiry Strategy

Guided Inquiry Strategy has been adopted as the method for enhancing students’ conceptual understanding of the fundamental concepts of Solid State Physics. This Strategy is based on the Constructivist theory of teaching and learning.

Constructivism allows the learner to get actively (not passively) involved in constructing meaning of a particular concept rather than merely memorising the facts associated with it. It takes into account students’ prior ideas which may affect the meaning making of the present concept. Teacher, thus has an additional responsibility of identifying and moulding these prior ideas in a manner such that it leads the learner towards a better understanding of the concept[49]. Constructivist Learning, has been referred to, as having following tabulated features, listed in What is Constructivism? Attributes[49], for knowledge construction. Constructivism thus aims at providing appropriate level of instruction from the teacher rather than direct instruction or minimal instruction[50]. The crucial aspect of the constructivism based classroom environment, is the inclusion of the students’ prior understanding in the course of building new understanding.

Guided Inquiry Strategy (GIS) is one such approach to make students construct their own knowledge under the guidance of the teacher who acts as a facilitator. On the basis of

<table>
<thead>
<tr>
<th>Nature of Constructed Knowledge</th>
<th>Nature of learners</th>
</tr>
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<tbody>
<tr>
<td>Physical</td>
<td>Learners are involved in active Learning</td>
</tr>
<tr>
<td>Symbolic</td>
<td>Learners are making their own representations of actions</td>
</tr>
<tr>
<td>Social</td>
<td>Learners convey their meaning making to others</td>
</tr>
<tr>
<td>Theoretical</td>
<td>Learners try to explain things they don’t completely understand</td>
</tr>
</tbody>
</table>
Information Search Process, Kuhlthau and Todd have proposed the following seven steps of guided inquiry:

1. **Initiation**: The teacher initiates the inquiry by posing a question based on the concept to be probed.
2. **Selection**: Based on the pre-existing knowledge, the students select the answer.
3. **Exploration**: Students explore the initiating question further and try to explore what they don’t know.
4. **Formulation**: Based on the results of their exploration, they formulate notions regarding the concept.
5. **Collection**: Under the guidance of the teacher, students collect evidences for the theoretical conceptualization formulated by them.
6. **Presentation**: The formulated notions are then shared amongst the peer group.
7. **Assessment**: Students themselves assess what has been presented and after discussion amongst the peer, reach the conclusion.

As mentioned above, each step has to be carefully planned and executed under the constant guidance of the teacher.

### 1.7 Methodology of the present Research

The present research has been conducted incorporating the following steps:

1. **Shortlisting the crucial topics on the basis of following criteria**
   - Suggestions by Teacher Experts who have been teaching the subject of Solid State Physics at Undergraduate level over a period of time.
   - Topics covered under the Syllabi of the subject of Solid State Physics followed by various national and international educational institutes and universities.
2. **Exploring the Pre-conceptions related to shortlisted elementary ideas of SSP amongst**
students

3. Developing Intervention Modules along with Expected Learning Outcomes based on Revised Bloom’s Taxonomy (RBT) as well as devising Concept Inventory of Elementary Ideas in Solid State Physics (CIEISSP)

4. Validating the Intervention Modules and Concept Inventory of Elementary Ideas in Solid State Physics (CIEISSP) through expert opinion (Content Validity) and iterative administration on students (Face Validity)

5. Dividing the CIEISSP into Pre-Test and Post-Test

6. Administering Pre-test; Educational Intervention; Post-Test

7. Preparing Conceptual Chronology based scoring key for Pre-test and Post-Test based on RBT

8. Data Analysis and Interpretation

1.8 Limitations of the Study

The following aspects limit the scope of the present research:

1. The study is limited to (Fifth Semester) UG and (First Semester) PG students i.e. those pursuing Graduation or Masters course in Physics (and few who were pursuing First Semester of B.Ed.)

2. The study is limited to the Educational Institutes of Kangra District of Himachal Pradesh

3. The present study takes into account a limited number of elementary concepts associated with Crystal Structure

1.9 Subsequent Chapters

Given is a brief description about the remaining chapters of the thesis.
Chapter 2  The chapter elaborates the process of exploring the Preconceptions amongst students, related to the elementary ideas of SSP.

Chapter 3  This chapter discusses the methodology involved in the preparation of GIS based Intervention Modules, the activity to arrive at 3-D Bravais Lattices from 2-D Bravais Lattices and a proposed Simulation to determine the structure of an element and to calculate the Cohesive Energy of the element

Chapter 4  The chapter is a description about the development of the Concept Inventory of Elementary Ideas in Solid State Physics (CIEISSP)

Chapter 5  This chapter is about the implementation phase of the CIEISSP as Pre-Test, GIS based Intervention Modules and CIEISSP as Post-Test on the UG and PG students of various institutes of Himachal Pradesh

Chapter 6  This last chapter is about detailed analysis of the data collected, interpretation of the analysis, educational implications based on the analysis and future research work.

References


