EFFECTIVENESS OF A METACOGNITIVE STRATEGY INSTRUCTION ON PROBLEM SOLVING SKILLS IN PHYSICS AMONG HIGHER SECONDARY SCHOOL STUDENTS IN KERALA

Thesis

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Chapter I

INTRODUCTION

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The central point of education is to teach people to think, to use their rational powers, to become better problem solvers (Gagne,1980). Like Gagne, most psychologists and educators regard problem solving as the most important learning outcome of life. Hence, education in the sciences must address the crucially important task of teaching students to become proficient problem solvers.

One method that teachers use to reach educational goals is to involve students in problem solving (Foshay & Kirkley, 2003). Problem solving is important as it promotes higher order thinking and accelerates the transfer of knowledge to novel situations (Mayer, Salorey, & Caruso, 2008). Since problem solving is a very sophisticated cognitive skill, understanding and teaching problem solving is practically important and intellectually challenging (Larkin & Reif, 1979).

The most pervasive assumption of instructional design is that different learning outcomes necessitate different conditions of learning (Gagne, 1980). Instructional design research and theory has devoted too little attention to the study of problem solving processes. Problem solving has never been sufficiently acknowledged, or articulated in the instructional design literature (Jonassen, 2000).

Different approaches to instruction present different perspectives and different level of emphasise on problem solving. Information processing theories conceive of learning outcomes as generalizable skills that can be applied across content domains, while constructivism and situated cognition argue for the domain specificity of any performance and therefore recommend embedding instruction in some authentic context (Jonassen & Land, 2000). Models of problem solving whether it is general or domain specific involve a defined cognitive sequence requiring the students to represent the problem, search for a solution, and then implement the solution (Bransford & Stein, 1984; Newell & Simon, 1972). Neverthless, Problem solving tasks may be mentally demanding and time consuming, particularly as students develop problem solving skills.

Classroom settings do not offer the luxury of unlimited instructional time. Frequently teachers are faced with the dilemma of providing instructional tasks that promote higher order thinking within rigid time constrains. They ask the students to complete demanding problem solving tasks in limited time (Slavin, 1996). As a result, students experience cognitive overload and inefficient or ineffective use of mental resources (Mayer & Moreno, 2003). Identification of these difficulties during instruction and the urge to develop in young minds reflective thinking capacity resulting in efficient problem solving in physics lead to the present study. The study aims to develop an instructional strategy, which facilitate critical and reflective thinking along with the internalisation of concepts, by this means, building better problem solvers.

Need and Significance of the study

Developing and enhancing problem solving abilities of students have long been important objectives of science education. Problem solving ability is generally viewed as the ability to think critically, to reason analytically and to create productively. All these involve quantitative, communication, manual and critical response skills (American Association for the advancement of science, 1993).

To be successful in problem solving, students need to have some background domain specific knowledge and they need to possess certain science process skills. Many researchers have suggested employing different modes of problem solving associated models of instruction to improve students' creative/critical thinking, problem solving ability and science process skills (Basaga, Geban, Tekkaya, 1994; Chang, 2001;Geban, Askar, & Ozkan, 1992;Germann, 1989;Tobin & Cape, 1982).

Researchers (Mateycik, 2009 ; Solaz-Portoles, & Sanjose, 2007) are of the opinion that knowledge domain should be properly interconnected and structured to facilitate problem solving. Further study of physics plays a major indirect role in inducing rational thinking, youthful enthusiasm, self-control, curiosity, self-discipline and boldness. Therefore, physics must be taught as a connected fabric of knowledge in which something learnt in one place proves useful somewhere else and something discovered later throws light back on something worked with earlier.

It is found that, conceptual knowledge and problem scheme knowledge are good predictors and have independent effects on problem solving ability (Friege & Lind, 2006). In addition using external representation through symbols and objects to illustrate a learners' knowledge and the structure of that knowledge can facilitate complex cognitive processing during problem solving (Solaz-Portoles, & Sanjose, 2007). Hence, explicit teaching in organizing the knowledge and relating metacognitive knowledge and skills to the conceptual knowledge are important (VanSickle & Hoge, 1991). The present study employs concept maps on selected topics to present the knowledge domain required to solve problems. Hereby an attempt is made to organise the conceptual knowledge so that students can internalise the required concepts. This may facilitate their easy retention and use during problem solving.

Problem solving implies a wide range of cognitive and metacognitive processes, like invention, exploration, experimentation, reflection in action (Pacey, 1999; Rowe, 1987; Waks, 2001). It is characterised as a highly creative and multi-faceted course of action, where, reflection, evaluation and knowledgeable decision making appear as essential components.

Most curricular transactional models for problem solving have at least four steps: problem identification, exploration of alternative solutions, realization of the chosen solution and its evaluation (Hutchinson & Karsnitz, 1994; Johnsey, 1995). In some cases, feedback path among stages are suggested. However, due to implementation constrains related to time, logistics, clarity of teaching goals and teachers' linear perception of the process, these models rarely transcend the textbook to be activated in the classroom. There is little room left in actual classroom situation for reflection, formative evaluation and resourceful decision making beyond the detailed guidelines prescribed in the range of teaching materials. Curricular transactions seems to ignore pedagogical approach towards problem solving which encourage (individual and group) student controlled knowledge construction processes within resourceful learning environments (Fleer, 2000; Hennessy & Murphy, 1999; Resnick & Ocko 1991). The present study attempts to fill the gap between the fulfilment of curricular objectives and its translation in classroom by developing an instructional strategy that enhances reflective thinking while solving problems.

Recent studies on enhancing domain specific problem solving strongly recommend the use of metacognitive strategies. They argue that students may not know how to use the instruction effectively, thus they might benefit from metacognitive instruction on how to learn (Roll, Aleren, McLaren, Ryu, Baker, & Koedinger, 2006). In addition, if metacognition is taught to school students their problem solving skills will be improved (Mestre, 2002). This is because high metacognitive skills can compensate for overall ability by providing certain knowledge about cognition (Swanson, 1990). When new information and domain specific knowledge are held constant, reflective thinking processes that encourage elaboration on a problem are instrumental in providing the most efficient problem solving. Problem solving procedure is explicitly taught in the present study. This may help the students in elaborating their own strategies while solving the problems and may encourage reflective thinking.

Researchers (Abdullah, 2006; Veenman & Spaans, 2005) have developed a more or less similar list of metacognitive skills related to problem solving which include orientation, planning, evaluation and elaboration. Metacognitive skills or reflective practice can be described as the “sign of maturity” in problem solving. Therefore, students who developed the ability to ascertain when to make metacognitive decision and elicit these decisions, out-performed other students in ability to solve word problems (Teong, 2003).

Socio-cognitive theories hold that knowledge is socially constructed through the process of interaction and activity among individuals. According to this perspective individuals' cognitive skills develop in social context (Leont’ev, 1932; Luria, 1928, 1932; Vygotsky 1929, 1978). Individuals' skill development is guided by others, usually parents, teachers, or more capable peers. They are said to mediate the learning by guiding the participation of the learner. As the individual develops in a particular activity or skill, the mediating other progressively points more of the responsibility for managing the activity to the learner. During this "guided participation" (Rogoff, 1990) the other builds on what the learner already knows and guides the learning. In this way the learner internalizes or "appropriates" (Rogoff, 1990) knowledge and meanings. The learner not only appropriates the content involved in an activity, but also gradually internalizes the process (the procedures, skills and strategies) involved.

In this view a number of researchers (Chi & Hausmann, 2008) advocate that metacognitive strategies will be more effective if there is peer interaction. Peer interaction can provide a framework where monitoring of the strategies used in the problem solving processes can be continuously presented, considered, re-evaluated and modified in terms of each partners' perspective (Vansickle & Hoge, 1991). Further, working in pairs tends to decrease the frequency of poor metacognitive strategies. It appears that the social accountability increase the frequency of effective learning strategies, that in turn increased learning gains (Chi & Hausmann, 2008).There are two experimental groups in the present study. Other factors remaining a constant, one of the groups is taught in an environment that encourages peer interaction. The objective is to compare the proposed teaching strategy in the presence and absence of peer interaction.

Many authors have demonstrated numerous factors effecting problem solving skills. These include fluid intelligence and crystallized intelligence (Horn, & Cattell, 1967), memory and metamemory (Kreutzer, Leonard, & Flavell, 1975), reflection impulsivity. Schoenfeld (1985) argued that four factors are necessary and sufficient for understanding the quality and success of problem solving, viz., (1) the knowledge base, (2) Problem solving strategies, (3) Control: monitoring and self regulation, or metacognition and (4) Beliefs and the practices that give rise to them.

More recent literature review did not result in a much different taxonomy on the factors influencing problem solving performance, as can be concluded from the broad taxonomy of problem solving attributes put forward by Carlson and Bloom (2005). The dimensions of the taxonomy are (1) Resources, ie., the conceptual understandings, knowledge, facts and procedures. (2) Control, ie., the selection and implementation of resources involving, planning, monitoring, decision making, conscious metacognitive acts likewise (3) Methods, ie., the general strategies used while working a problem, like constructing new ideas, carrying out computations etc. (4) Heuristics, ie., more specific procedures and approaches used when working a problem, like observing symmetries, altering the given problem so that it is easier etc. (5) Affect ie., attitudes (enjoyment, motivation, interest), beliefs (self confidence, pride, persistence, etc.), emotions (joy, frustration, impatience, etc.) and values/ ethics (mathematical intimacy and integrity).

Since all these factors and processes effects the previous problem solving skills of students, the investigator, instead of assessing each of these factors independently, made the study concise by assessing previous problem solving ability in physics (in the area of mechanics) and matched the two experimental and control groups based on its measures.

Research on the influence of metacognition further evidence metacognition offers a significant path to critical thinking (Hargrove, 2013; Hargrove & Nietfeld, 2014; Magno, 2010). Critical thinking, which involves the deliberate use of skills and strategy that increase the probability of a desirable outcome in turn promote transfer to novel contexts (Halpern, 1998).

In addition, metacognitive instruction itself seems to have a positive impact on dealing with both problems of transfer and durability as it makes students responsible for their learning (Georghiades, 2000). These views persuaded the researchers in present study to investigate the effect of the newly developed metacognitive strategy instruction on the ability of students to transfer learned skills on problem solving to novel tasks.

Thus this study investigates the effectiveness of the newly developed metacognitive strategy instruction on problem solving skills of students both in analogous problems (problems from the same content area and similar to those solved in the classroom) and transfer problems (problems from other content areas of mechanics).

Statement of the Problem

"Effectiveness of a Metacognitive Strategy Instruction on Problem solving Skills in Physics among Higher Secondary School Students in Kerala"

The present study tests the effectiveness of instruction through a newly developed Metacognitive Strategy on Problem Solving Skills in Physics among Higher Secondary School Students in two different situations in a classroom, ie., students learning under the guidance of teacher in an environment driven by peer interaction and students learning under the guidance of teacher in the absence of peer interaction.

Definition of the Key Terms

1. Metacognitive Strategy Instruction

Metacognitive Strategy Instruction refers to an instructional strategy developed by the researcher to enhance problem solving skills in students. It consists of four phases. Each of these four phases contains sub-phases or steps. Further several phases may be included in a single lesson. This is an instructional strategy and at the same time, the strategy is explicitly taught to the pupil by pinpointing each phase of this strategy as it occurs in the classroom process. Hence the name Metacognitive Strategy Instruction was given.

The instructional strategy consists of the following phases and sub-phases.

I. Presentation of the knowledge domain

1. Presentation of concept map
2. Explanation of concepts and their relationships
3. Exemplification of the use of concepts to solve problems

II. Presenting the problem

III. Problem solving procedure

1. Surface Representation
2. Structure Representation
3. Planning the Solution
4. Implementing the plan

IV. Metacognitive analysis

1. Error Analysis
2. Monitoring the Procedure
3. Analogical Problem Solving

This strategy is instructed to the students both in individual problem solving situation and in problem solving situation mediated by peer interaction.

2. Problem Solving Skills in Physics

This term involves three components.

a. Analogical problem solving ability

This refers to the ability to solve problems similar to those worked out in the classroom.

b. Problem solving skills in physics

This refers to the ability to solve problems from content domain in physics, which was not directly discussed in the classroom.

c. Use of metacognitive strategies in problem solving

This refers to the attainment of various component skills required for understanding and solving a given problem. The component skills identified in the study are:

1. Representing the problem situation
2. Planning the solution
3. Implementing the plan
4. Evaluation of the solution obtained.

These component skills are assumed hierarchical, and hence are done in invariant sequence.

Objectives of the Study

This study intends to develop and test the effectiveness of an instructional strategy to foster problem solving skills in physics among higher secondary school students. The study examines the effectiveness of Metacognitive Strategy Instruction at three levels namely,

1. Peer Interacting Metacognitive Strategy (PIMS)
2. Metacognitive Strategy (MS)
3. Conventional Strategy

To accomplish this major objective, the study has set the following specific objectives.

1) To test the effect of Metacognitive Strategy Instruction [Peer Interacting Metacognitive Strategy (PIMS) Instruction, Metacognitive Strategy (MS) Instruction, Conventional Strategy (CS)] on Analogical Problem Solving ability in Physics among Higher Secondary School Students.

2) To test whether the analogical problem solving ability is significantly higher for PIMS groups than that of the control group.

3) To test whether the analogical problem solving ability is significantly higher for MS group than that of the control group.

4) To test whether the analogical problem solving ability is significantly higher for PIMS group than that of the MS group.

5) To test the effect of Metacognitive Strategy Instruction [Peer Interacting Metacognitive Strategy (PIMS) Instruction, Metacognitive

Strategy (MS) Instruction, Conventional Strategy (CS)] on Problem Solving Skills in Physics of Higher Secondary School Students.

6) To test whether the problem solving skills in physics are significantly higher for PIMS group than that of the control group.

7) To test whether the problem solving skills in physics are significantly higher for MS group than that of the control group.

8) To test whether the problem solving skills in physics are significantly higher for PIMS group than that of the MS group.

9) To test the effect of Peer Interaction [Peer Interacting Metacognitive Strategy (PIMS) Instruction, Metacognitive Strategy (MS) Instruction] on the use of Metacognitive Strategies in Problem Solving among Higher Secondary School Students .

10) To test whether the use of metacognitive strategy instruction is significantly higher for the PIMS group than that of the MS group.

11) To estimate the relative efficiency of the four component skills of metacognitive Strategy on Problem Solving Skills in Physics viz.,

    i. Representing the problem
    ii. Planning the Solution
    iii. Implementing the plan
    iv. Evaluating the result

Research Questions

In order to clarify the broad objectives of the study, each of the specific objectives are formulated as research questions to make them more specific. They are listed below:

1) Can Metacognitive Strategy Instruction [Peer Interacting Metacognitive Strategy (PIMS) Instruction and Metacognitive Strategy (MS) Instruction] significantly improve Analogical Problem Solving ability in Physics among Higher Secondary School Students? If so, can Peer Interacting Metacognitive Strategy Instruction develop analogical problem solving ability better than Metacognitive Strategy Instruction?

2) Can Metacognitive Strategy Instruction [Peer Interacting Metacognitive Strategy (PIMS) Instruction and Metacognitive Strategy (MS) Instruction] significantly improve Problem Solving Skills in Physics among Higher Secondary School Students?, if so can Peer Interacting Metacognitive Strategy Instruction develop problem solving skills in physics better than Metacognitive Strategy Instruction?

3) Can Peer Interaction [Peer Interacting Metacognitive Strategy (PIMS) Instruction] significantly improve the Use of Metacognitive Strategies in Problem Solving of Higher Secondary School Students (over Metacognitive Strategy Instruction)?

4) Which component skills in metacognitive strategy of problem solving viz.,

   i. Representing the problem
   ii. Planning the solution
   iii. Implementing the plan and
   iv. Evaluating the solution

   Contribute significantly to the problem solving skills in physics in students instructed on Metacognitive Strategy?

Hypotheses

The research questions were reformulated in to the following hypotheses.

1) Metacognitive Strategy Instruction [Peer Interacting Metacognitive Strategy Instruction (PIMS) and Metacognitive Strategy (MS) Instruction] has significant effect on analogical problem solving ability in Physics among Higher Secondary School students.

2) Peer Interaction in Metacognitive Strategy Instruction will significantly enhance analogical problem solving ability in physics among Higher Secondary School students.

3) Metacognitive Strategy Instruction [Peer Interacting Metacognitive Strategy (PIMS) Instruction and Metacognitive Strategy (MS) Instruction] has significant effect on Problem Solving Skills in Physics among Higher Secondary School Students.

4) Peer Interaction in Metacognitive Strategy Instruction will significantly enhance problem solving skills in physics among Higher Secondary School students.

5) Peer Interaction in Metacognitive Strategy Instruction will significantly enhance the use of metacognitive strategies in problem solving in physics among Higher Secondary School students.

6) The component skills in metacognitive strategy of problem solving viz.,

   i. Representing the problem
   ii. Planning the solution

iii. Implementing the plan and

iv. Evaluating the solution

will contribute significantly to the problem solving skills in physics of the PIMS group and MS group.

Methodology

The study employed a quasi-experimental, non-equivalent pre-test post-test control group design to test the effectiveness of a metacognitive strategy instruction on the problem solving skills in physics among higher secondary school students of Kerala. This involves development of the instructional strategy, teaching three units in physics using this instructional strategy and at the same time instructing the strategy directly to the students and testing its effectiveness on domain specific problem solving.

Variables

The study is quasi-experimental. It employs independent variable, dependent variable and control variable.

Independent variable

Independent variable of this study is metacognitive strategy instruction, with three levels viz.,

1. Metacognitive Strategy
2. Peer Interacting Metacognitive Strategy
3. Conventional Strategy (control)

Dependent variable

The effectiveness of the independent variable on problem solving skills in physics is studied. The study identified seven dependent variables, namely,

1. Analogical Problem Solving Ability
2. Problem Solving Ability in Physics
3. Use of Metacognitive Strategy for Problem Solving

The four component skills in using metacognitive strategy for problem solving are also study as dependent variables. These sub variables are :

1) Representing the Problem Situation
2) Planning the Solution
3) Implementing the Plan
4) Evaluation of Solution

Control variable

All the three groups namely PIMS, MS and CS were matched based on their Previous Problem Solving Ability. Hence the control variable in this study is the previous problem solving ability of pupils. All the three groups were instructred by the investigator and hence teacher factor is considered constant.

Design of Experimentation

Non-equivalent pre-test post-test control group design which can be debited as follows was employed in this study.

G_1 : O_1 X_1 O_4 O_7 O_{10}

G_2 : O_2 X_2 O_5 O_8 O_{11}

G_3 : O_3 C_1 O_6 O_9

O_1, O_2 and O_3 are the Pre-tests on the dependent variable [Previous Problem Solving Ability in Physics]

O_4, O_5 and O_6 are the Post-tests, viz., Analogical Problem Solving Agility in Physics.

O_7, O_8 and O_9 are the Post tests, viz., Problem Solving Skills in Physics.

O_{10}, and O_{11} are the Post tests on the Use of Metacognitive Strategies in Problem Solving involving Component skills (representing the problem, planning the solution, implementing the plan, evaluating the solution)

G_1 is the First Experimental Group (PIMS group)

G_2 is the Second Experimental Group (MS group)

G_3 is the Control Group

X_1 is the Application of First Experimental Treatment (Peer Interacting Metacognitive Strategy)

X_2 is the Application of Second Experimental Treatment (Metacognitive Strategy)

C_1 is Application of Control Treatment (Conventional Strategy) of teaching problem solving.

All the three groups are matched based on their previous problem solving ability.

Sample for the Present Study

Higher Secondary School Studnets of Kerala comprise the population of the study. Out of the fourteen districts in Kerala, Kozhikode district was randomly selected for the study. Three Higher Secondary Schools with students of comparable socio-economic status and educational background were choosen from Kozhikode district. These were Farook Higher Secondary School, Farook College; Government Ganapath Vocational Higher Secondary School, Feroke; and Government Vocational Higher Secondary School, Cheruvannur.

Sample used for standardization of tools

Out of three schools, two schools namely Farook Higher Secondary School and Government Ganapath Vocational Higher Secondary School were randomly assigned for providing sample for standardization of tools. Each of these schools had four grade 11 classes. There were around 50 students in each of these eight classrooms. From among the eight classes, three classes were randomly selected as standardization sample. In these three classes two (out of four) were from Government Ganapath Vocational Higher Secondary School and one class was (out of four) from Farook Higher Secondary School. In these three classes same tests were employed. Out of around 150 students who were administered the test, 112 students gave data which was complete in all respects. Therefore these 112 students were used as sample for standardization of tests.

Sample used in experiment

For conducting experiment, Government Vocational Higher Secondary School, Cheruvannur was randomly choosen. There were three grade 11 classes with around 50 students in each class. Pre-test (Previous Problem Solving Ability) were conducted in all the three classes. After matching the three groups on Previous Problem Solving Ability, 38 students each from the three classes were choosen for the intervention. The three groups of 38 studnets each were then randomly assigned into two experimental (PIMS and MS) and control (CS) group.

Tools and Techniques

The tools were developed and used to quantify the dependent and control variables. In total, four Tests on Problem Solving especially in the field of mechanics to be administered at different stages of the study were developed. Two of these tests are parallel and were used as the pre-test and post-test of problem-solving ability. Thus, the three separate tests developed were the following.

1. Tests of Problem-Solving Ability (Two Parallel Forms; Previous Problem Solving Ability, and Analogical Problem Solving Ability,).

2. Test on Problem Solving Skills in Physics.

3. Diagnostic Test on Component Skills in Problem Solving (Use of Metacognitive Strategies in Problem Solving)

   This diagnostic test consists of four sub-tests, viz.,

1) Test on the Ability to Represent Problem situation
2) Test on the Ability to Plan Problem Solving Procedure
3) Test on the Ability to Implement Problem Solving Procedure
4) Test on the Ability to Evaluate Solution to a Problem

In addition to the tools, a metacognitive strategy instruction was developed to enhance problem solving skills in physics among higher secondary school students. It consists of the following four phases:

I. Presentation of the Knowledge Domain

This phase involves three sub-phases.

1. Presentation of Concept map

The different concepts and their relationships are first represented in the form of a concept map. One concept map is prepared to cover a unit. It encompasses all the relevant equations for solving the problems to follow. The teacher presents one concept map at a time. This will help students to memorise the required concepts and principles and to identify their interrelationship.

2. Explanation of Concepts and their Relationships

Each concept is discussed and compared and contrasted with other similar concepts to develop a comprehensive understanding. The principles and equations connecting the various concepts/ physical quantities are explained. The assumptions made while using the equations are also made clear to the students.

3. Exemplification of the use of concepts to solve problems

In order to clarify the use of concepts and their relationships in solving problems in physics, values of physical quantities are set in everyday life situations and the equations are used to determine unknown physical quantities.

II. Presenting the Problem

Well- structured academic story problems are presented from three units of Newtonian Mechanics, namely, ‘Motion in a Straight Line’, ‘Motion in a Plane’, ‘Laws of Motin’.

Mathematical values are embedded in a brief explanation of an incident, case or situation, from which learners identify key words in the story, select the appropriate algorithm and sequence for solving the problem and apply the algorithm.

III. Problem Solving Procedure

In this phase students solve the problems under the guidance of the teacher. The maps are exhibited throughout the class periods in which problems are solved. Problem solving procedure follows four steps.

1. Surface Representation

This step requires the semantic comprehension of relevant textual information and the capacity to visualize data. This involves the generation of an initial problem description and qualitative analysis designed to facilitate the subsequent construction of a problem solution. Students identify the information specified and wanted in the problem. These are then expressed in the form of a graph or a diagram.

2. Structure Representation

The knowledge base required to solve the problem are presented before students in the form of a concept map. Students generate a theoretical description of the problem by identifying the relevant principles and relations needed for qualitative analysis and later solution of the problem.

3. Planning the Solution

After listing the relevant principles and relations, values of the physical quantities provided in the story are identified. Those that are not explicitly given in the story are generated by deriving the required relations. These derived relations are scrutinised for errors if any. The appropriate algorithm to solve the problem is designed at this stage.

4. Implementing the Plan

The values of all the required physical quantities explicitly given in the story and those generated are substituted in the identified principles and relations. The result or solution is then generated, following the already designed algorithm.

IV. Metacognitive Analysis

This stage is designed to facilitate reflective thinking among the learners. Here, students analyse quantitatively and qualitatively the solution obtained. The learners make a quick review of the different stages through which they passed. They discuss the constrains faced and how the solution path was opened. Metacognitive Analysis involves three stages

1. Error Analysis

Here the learners check whether the derived equations are dimensionally consistent and whether the units used for different physical quantities are consistent. Then the learners give a logical reasoning for the solution obtained. They should explain how the solution is practically feasible.

2. Monitoring the Procedure

At this stage, the teacher asks several questions, to help students review the cognitive processes underwent by them. Learners openly discuss the constraints faced by them, the errors that occurred while solving the problem and strategies successfully adopted by them. The stages in problem solving are enumerated after each successful problem solving. These steps assured thorough understanding of the procedure by the learner to follow them in future problem solving.

3. Analogical Problem Solving

Here the students are given a problem similar to that they have just solved under the guidance of the teacher. In Metacognitive Strategy Group, the students solve this problem independently. In Peer Interacting Metacognitive Strategy Group, small homogeneous groups of students (5 students in each group) solve the problem discussing the strategies within the group. Teacher maintains an environment of healthy competition among the peer groups.

Once the analogical problem is solved, the whole class discusses the solution obtained, assumptions made and the various strategies used to crack the problem.

Scope of the Study

This study identifies various component skills of problem solving, namely, representing the problem, planning the solution, implementing the plan and evaluating the solution by reviewing literature and classroom experience of the researcher in teaching problems in physics.

Following the identification of various component skills in problem solving, the study recognized an assortment of techniques to enhance these components among students. Integrating these techniques, this research developed an instructional strategy to boost reflective thinking and problem solving ability. Teachers in various fields of physics can adopt this instructional strategy and allied sciences for helping their students become better problem solvers.

The study developed reliable and valid tools for measuring problem solving ability in relation to concepts in mechanics (two parallel forms), the problem solving ability of students in Physics in general and for measuring the various component skills related to problem solving. Since these component skills are found to be hierarchical, the test can also be used for the diagnosis of problem solving abilities in students. These tools can further be used by teachers and students of Physics at Higher Secondary Level.

The study developed teaching modules covering three units in mechanics at higher secondary level giving due focus on problem solving and scientific process. The module consists of 30 lessons. Each lesson has duration of one hour. Every effort is made while preparing the module to enhance problem solving ability of students to make them a regular user of metacognitive strategies. Science teachers can use this module for better transaction of curriculum in their classroom. The module is self-instructing. Therefore, students can use this module for independent learning.

The domain selected in the present study is Mechanics. Mechanics is a branch of physics that has scope for innumerable types of problems. Every other branch of physics fundamentally gravitates towards Mechanics. Though the subject is more concrete and directly related to our day-to-day life, students seem reluctant to attempt to solve problems in mechanics. They perceive Mechanics problems as most difficult and challenging. The strategy developed in this study will play a vital role in removing this prejudice notion on the subject and makes it easily viable. The modules and two parallel tests of Problem Solving Ability developed will be helpful for teachers and students in this regard.

The study examines the effectiveness of the strategy both at individual level and in small groups. It shows evidence for the better utilisation of the strategy in an environment of peer interaction. Thereby this study illuminates the role of peer-communication in academic performance, especially in relation to higher secondary school physics, though the findings from this study can be fruitfully extended to teaching-learning of other sciences in all levels of education.

Delimitations

Conceptualisation of the study is done by bearing in mind the higher secondary/ vocational higher secondary school student population in government and government aided sectors in kerala. However for practical reasons the sample is drawn from among standard XI students only. Further the experimental sample is drawn from a single urban government school in Kozhikode district. Though the school is geographically located in Kozhikode, the student population in school, especially in XI and XII classes have almost equal representation from Malappuram and Kozhikode districts. Since these districts are geographically located nearly the centre of the Kerala state, the findings of the study will be generalizable to the larger school population of the state, and to those with similar socio- educational situations.

Review of literature reveals that there are different types of problem solving, broadly classified in to well- structured and ill- structured. Since the researcher found well- structured problem solving as more concrete, systematic, academic oriented and convenient to discuss in classroom situation, she selected only well- structured domain specific problems. Further, the researcher herself has an academic orientation in the discipline, physics. So she delimited her study to a branch of physics ie., mechanics. Since it is a classical branch of physics, the solution strategies developed will be generalisable to all other branches of physics.

Literature opens up to innumerable number of problem solving strategies. Most of these strategies are overlapping though. Only Metacognitive strategy, which the researcher assumed determinant in reflective thinking and transfer value, was selected. Some selected techniques like the use of concept maps, analogical problem solving and peer interaction was incorporated in to the instructional strategy to give it a finishing touch. Such a selective approach to techniques was felt appropriate from the pilot studies conducted by the researcher.

The three groups employed for the study could be matched on the basis of a number of factors that affect problem solving like, domain knowledge, intelligence, critical thinking likewise. The inability to make concise these factors to a manageable few, the researcher decided to make the study compact by matching the groups based on a variable that will be effected by all these factors, ie., previous problem solving ability.

Chapter II

REVIEW OF RELATED LITERATURE

- ***Overview of Problem Solving: Concept, Process and its Facilitation via Metacognition and Colaboration***
  - *Problem Solving: Definitions, Strategies*
  - *Factors Effecting Problem Solving*
  - *Instructional Designs in Problem Solving*
  - *Knowledge Domain in Problem solving: Role of Concept Maps*
  - *Metacognitive Strategies in Problem Solving*
  - *Collaborative Problem Solving*
- ***Studies on Problem Solving, Metacognition and Concept Maping***
  - *Problem Solving in Academic Contexts*
  - *Metacognitive strategies in Problem Solving*
  - *Collaborative Problem Solving in Teaching-Learning Environments*
  - *Nature of Knowledge Domain Needed for Problem Solving: Role of Concept maps in Learning Teaching and Problem Solving*

Practically each person in their everyday and professional lives habitually solves problems. Therefore, it is indispensable to understand the width of problem solving behavior well enough to engage and support learners in them.

This chapter deals with review of literature mostly drawn from journals sourced in internal. As much Indian studies on problem solving and metacognition were not available in online journals, Indian journals and dissertations were purposely reviewed from libraries.

Literature were searched on problem solving with special focus on Physics problem solving, metacognition and metacognitive strategies to enhance problem solving, developing conceptual knowledge especially using conceptness and on the role of peer interaction while teaching problem solving.

There were numerous studies on problem solving, most of them focusing on mathematics problem solving. Though the concept of metacognition was developed in 1970's, this construct is found extensively studied and investigation of its role in facility ating problem solving is a decent trend. Comparatively lesser studies were conducted on the nature of knowledge domain required and the role of conceptmaps on problem solving. There are still fewer studies that investigate role of peer interaction while teaching problem solving and the studies evidence contradictory view points.

Comprehending the cognitive processes involved in problem solving and summarizing the factors effecting problem solving based on the reviewed literature was quiet a difficult task. The review makes evident the absence of a universal problem solving procedure that facilitate all types of of problems. A meta analytic summary on cognitive processes and factors effecting problem solving was not found in the available extent literature on the topic.

The reviewed literature is presented in this chapter under two broad categories viz., a theoretical overview and studies on problem solving. Theoretical overview includes problem solving, metacognitiion, nature of knowledge domain and its integration and peer interaction. Studies on problem solving are further categorized as studies on (1) problem solving, (2) metacognitive strategies in problem solving, (3) claborative problem solving, and (4) nature of knowledge domain needed for problem solving and the role of concept maps in learning teaching and problem solving.

Overview of Problem Solving: Concept, Processes and its Facilitation via Metacognition and Collaboration

This section involves definition, strategies, effecting factors and instructional strategies on problem solving. The section also deals with the nature of knowledge domain needed and metacognition and collaboration facilitate problem solving.

Problem Solving: Definitions and Strategies

It is important to define problem solving in order to teach problem solving in classroom (Klahar & Dunbar, 1988; Oser & Baerisowyl, 2001). A few definitions of problem and problem solving proposed by different psychologists and educationalists are presented below.

> A problem is an unknown entity in some situation. Finding the unknown is the process of problem solving. A problem can also be considered as the difference between a goal state and a current state.

Problem solving is then any goal directed series of cognitive operations (Anderson, 1980).

A problem is a situation that confronts the learner, that requires resolution, and for which the path to answer is not immediately known (Posamentier & Krulik, 2009).

A problem arises when there is a goal, but how to reach this goal is not known (Robertson, 2001).

A problem arises when figuring out how to do something different is needed (VanGundy, 2005).

Problem solving is an investigative task whereby the solver explores the solution path to reach a goal from given information (Dhillon, 1998).

Problem solving is formulating new answers, going beyond the simple application of previously learned rules to create a solution (Woolfolk, 1993).

In a problem solving situation, the experimenter ideally knows the solution, but does not know how to reach it (Oser & Baeriswyl, 2001).

Problem solving is cognitive processing that aims at accomplishing certain goals when the solution is unknown (Mayer & Wittrock, 1996).

Problem solving is a complex, multi-layered skill, and not one that most students can be expected to develop unaided (Balton & Ross, 1997).

These definitions on problem and problem solving reveals that a problem occurs when the person encounters a stimulus for which he/she does not have an immediate correct response and solving the problem necessitates complex and reflective cognitive processes which can be learned.

The cognitive operations involved in problem solving have two vital aspects. First aspect is the construction of a mental or physical representation of the problem, known as the problem space (Newel & Simon, 1972). Such representations consist of structural knowledge, procedural knowledge, reflective knowledge, images and metaphors of the system, and executive or strategic knowledge (Jonassen & Henning, 1999). Second aspect of problem solving requires some activity based manipulation of problem space, like thinking (Jonassen, 2000). In short, problem solving is a reciprocal regulatory feedback between knowledge and activity (Fishbein, Eckart, Lauver, van Leeuwen, & Langemeyer, 1990).

Strategic problem solving processes/ models

Problem solving is a linear, hierarchical process. There are different approaches to explaining the problem solving processes. Psychologists and educationalists have identified several steps involved in the problem solving process that they propose will result in successful problem solving. These series of steps are referred to as models of problem solving.

Polya's (1957) prescription for solving problems consists of four steps. (1) Understanding the problem, i.e., recognizing what is asked for, (2) Devising a plan for solving the problem, i.e., responding to what is asked for, (3) Carrying out the plan, i.e., developing the result of the response, and (4) Looking back, i.e., evaluating what does the result tell. Each of these steps are considered as separate skills.

Similar to that put forward by Polya (1957), Reif, Larkin, and Brackett (1976) put forward another list of steps for solving physics problems, called the DPIC (describe, plan, implement, and check).

There are a number of information processing models of problem solving like General Problem Solver developed by Newel and Simon (1972). It is a classic General Problem Solver to explain problem solving process. It is an information processing model that specifies two sets of thinking processes namely, ‘understanding processes and ‘search processes.

Bransford and Stein (1984) put forward an information processing model of problem solving called the IDEAL problem solver. It describes problem solving as a uniform process of Identifying potential problems, Defining and representing the problem, Exploring possible strategies, Acting on those strategies, and Looking back and evaluating the effects of those activities.

Gick (1986) synthesized a number of information processing models of problem solving into a simplified model of problem solving process. It includes the process of constructing a problem representation, searching for solutions, and implementing and monitoring solutions. All these information processing models made an unsuccessful attempt to articulate a uniform theory of problem solving (Smith, 1991).

After the failure of information processing models to construct a uniform theory of problem solving, schema-theoretic conceptions of problem solving opened the door for different problem types by assuming that problem solving skill is dependent on a schema for solving particular type of problems. Existing problem schemas are the result of previous experiences in solving particular types of problems. This enables learners to proceed directly to the implementation stage of problem solving (Gick, 1986).

Information processing models of problem solving do not consider how problem complexity impacts cognitive demands and the spectrum of cognitive processes that underlie solution operations (Iiyoshi, Hannifin & Wang, 2005; Kim & Reeves, 2007; Lajoie, 2008; Merrienboer & Stoyanov, 2008). The current shift in instructional demands from learning objectives to authentic reference situations (Merrienboer, & Stoyanov, 2008) necessitates the need for more robust models of problem solving that accounts for how a problems complexity, structure, and context impact a learner's ability to manage multiple and competing cognitive demands.

Recently, investigators (Dogru,2008; Klahr & Dunbar, 1988; Klos, Henke, Kieren, Walpuski, & Sumfleth, 2008; Kneeland, 1999;Oser & Baeriswyl, 2001) have put forward several models for problem solving that include steps like problem presentation, discovery of problem, reformulation of problem task and exploring ways of solving the problem. To mention a few, Dunbar and Klahr (1988) model of Scientific Discovery as Dual Search (SDDS) is a well known psychological model that embraces essential steps for solving a problem in comparison to other models (Emden & Sumfleth, 2012). SDDS has been frequently taken up by science teachers and education researchers and it has been translated to sequences suitable for classroom practices (Emden & Sumfleth, 2012; Schreiber, They Ben & Schecker, 2009).

Oser and Baeriswyl's (2001) practical teaching theory provides concrete teaching steps for problem solving processes at school (Ohle, 2010). This model that focus on various cognitive processes like Identifying and formulating the problem, Activating prior knowledge, Defining and representing the problem, Formulating hypotheses, Exploring possible ways of solving the problem, Performing solving process and Looking back to hypotheses and evaluating are applicable both in cross-discipline situation and in domain specific situation.

External and Internal Factors Affecting Problem Solving

There are external and internal factors that affect problem solving (Smith, 1991). External factors include problem types, problem representations, cognitive tools and instruction. Internal factors include individual differences like familiarity, domain and structural knowledge, cognitive controls, metacognition, epistemological beliefs, and affective and conative elements. An account of these factors is attempted below.

1) Structuredness, complexity and abstractness of problem

Problems vary in terms of their structuredness, complexity, and abstractness.

a) *Ill-structured/ well-stuctured*: Based on the level of structuredness, problems can be classified as well-structured and ill-structured (Jonassen, 1997). Well structured problems are those we usually encounter in schools and universities. They are also called transformation problems (Greeno, 1978). They consist of a well defined initial state, a known goal state and a constrained set of logical operations or solving procedures. On the other hand, ill-structured problems are those that we usually encounter in our everyday and professional practice. They require the integration of several content domains. They process multiple solutions, solution paths, or have no solution at all (Kitchner, 1983). They can also be considered as unique human interpersonal activities (Meacham & Emont, 1989).

b) Simple/Complex: Problem complexity is determined by the number of issues, functions or variables involved in the problem, the degree of connectivity of its properties, the type of functional relationship among its properties and the stability among the properties of the problem over time (Funke, 1991). Problem complexity affects learners' abilities to solve problems (Halgren & Cooke, 1993). Complex problems involve more cognitive operations than simpler ones accommodating multiple factors during problem structuring and solution generation. This places a heavy burden on working memory (Kluwe, 1995). Further, complex problems contain multiple, interrelated components that are unclear or implicitly represented and are open to multiple approaches and solution paths (Spector, 2010). They require recognizing the problem, mental and external representations, devising arguments for solution, and monitoring progress (Belland, 2010; Belland, Glazewski, & Richardson, 2011; Cho & Jonassen, 2002; Dunkle, Schraw, & Bendixen, 1995; Larkin, 1983).

c) Domain specific/ Abstract Situated: Problems may be domain specific or abstract situated. Domain specific problem solving activities depend on the nature of the context or domain. They rely on cognitive operations that are specific to that domain and are referred to as strong methods (Mayer, 1992; Smith, 1991; Sternberg & Frensch, 1991). Abstract situated problem solving activities on the other hand do not rely on one specific domain. They employ domain generic strategies like means-ends analysis and are referred to as weak methods (Jonassen, 2000).

This classification of problems does not put them into watertight compartments. Usually complexity and structuredness overlap. Ill-structured problems can be complex like those emerging from everyday practices or they can be simple like the problem of selecting what to wear for different occasions. Similarly most well structured problems in math or science textbooks are simple; while there can be very complex well-structured problems like videogames. In the same way, domain specificity and structuredness overlap. The present study considers well-structured, domain-specific problems with moderate complexity for the level of learners.

To solve well-structure complex problems there are certain cognitive processes associated with the depth of content knowledge a learner need to master (Krathwohl, 2002). The revised Bloom's taxonomy of educational objectives (Anderson & Krathwohl, 2001; Bloom, Englehart, Furst, Hill, & Krathwohl, 1956) sequenced six categories of cognitive processes viz., remembering, understanding, applying, analyzing, evaluating and creating. Each of these categories are associated with the dimension of knowledge viz., factual knowledge, conceptual knowledge, procedural knowledge, and metacognitive knowledge. These cognitive processes and knowledge dimensions enable the teacher to specify what learner has to master, to solve each of the complex well-structured problems.

2) External and internal representations of the problem

Problems vary in terms of how they are represented to and perceived by the problem solver. Problems in everyday and professional context require the problem solver to separate important from irrelevant information and construct a problem state that includes relevant information (Goel & Pirolli, 1989).

An important function for designing for problem solving is deciding how to represent the problem. In formal learning situations like schools and universities, the instructional designers assume responsibility for constructing the problem space for learners. They do it by providing of withholding contextual cues, prompts or clues on information that need to be included in learners' problem space (Jonassen, 2000). In the present study, researcher includes proper representation of a given problem to facilitate problem solving as the first step in problem solving procedure. It also estimates how far the skill in representing a problem contributes to overall problem solving skills of the learner.

How problems are presented to the learner is an external factor influencing problem solving. Once the problem is presented to the learner, he/she perceives it and makes mental models of the problem situation. Development of mental models and their externalizations are dependent on individual's cognitive skills. Therefore they are internal factors that influence problem solving.

a) Mental models: A mental model is an internal representation of a system that the learner brings to bear in a problem solving situation (Jonassen, 2003; van Gog, Ericsson, Rikers, & Paas, 2005). It is developed through the application of different cognitive processes such as constructing, testing, and adjusting a mental representation of a complex problem (Derry, 1996). Through time experience and reflection on learning in the problem space, mental models gain strength, coherence and conceptual complexity (Jonassen & Strobel, 2006; Kim, 2012)

Mental models are rich, complex, interconnected, interdependent, multi-modal representations that are generally created in response to challenging problem situation. These mental models, when externalized can serve as an index for knowledge development, providing a window of how a learner thinks and reason (Kim, 2012; Spector, 2010). Henning (2004) put forward the perspective of distributed cognition, according to which knowledge develops through interactions between internal and external representations in the task environment.

b) External representations: According to Kim (2012) and Spector (2008) examination of external representation enables one to judge the progress of a learner in developing knowledge, reasoning about the problem situation, misconceptions and the need for support.

3) Computer based cognitive tools and learning environments

Cognitive tools are computer based tools and learning environments that are developed to function as intellectual partners with the learner to engage and facilitate critical thinking and higher order learning like problem solving (Jonassen, 1996). For example, Andes Intelligent Tutoring System (Andes, 2006), and Physlet which is a java application developed to deepen conceptual knowledge to aid problem solving (Christian & Belloni, 2004). They facilitate knowledge construction, support conceptual understanding, scaffold higher order cognitive tasks within complex learning environments and help learners enact a well-planned, prioritized set of actions for the solution of a problem (Funke, & Fresch, 1995; Jonassen, 2006; Pea, 1985; Salomon, Perkins, & Globerson, 1991).

Cognitive tools can also support metacognition through structuring the learning experience, providing scaffolds like prompts and feed back to support mental models, guiding students towards self regulation activities and dynamic information processing (Bannert & Reimann, 2011; Efklides, 2008; Funke & Frensch, 1995; Lee, Lim, & Grabowski, 2010)

4) Instruction

Teacher's instructional methods affect student performance (Good & Brophy, 2008). Earlier instruction focused either on content knowledge or on process skills, but today most countries simultaneously focus on both content knowledge and process skills (Kim & Hannafin,2011;Tang, Coffey, Elby & Levin, 2009). Owing to the increasing importance of science process skills, there is an increasing need to enhance students skill in observing, inferring, interpreting, investigating, problem-solving (Lederman & Lederman, 2012).

Student oriented instruction is essential to enable students to engage in scientific inquiry and problem solving processes in science classes (Hofstein & Kind, 2012). Class room instruction should also be so structured that students are first provided with a problem situation and then motivated and guided to plan, conduct and evaluate their own solution strategies (Berg, Bergendahl, Lundberg, & Tibell, 2003).

5) Familiarity with problem type

The strongest internal factor affecting problem solving ability is the solvers familiarity with the problem type. Experienced problem solvers have better developed problem schemas, which can be employed more automatically (Sweller, 1988). In spite of this, Gick and Holyoak (1980. 1983) observed that although familiarity facilitates problem solving, that skill seldom transfers to other kinds of problems. Hence, this study examines the effect of a metacognitive strategy instruction on the ability to solve analogical or familiar problems.

6) Domain and structural knowledge

Another internal factor effecting problem solving ability is the solvers level of domain knowledge. The integratedness of domain knowledge is called structural knowledge (Jonassen, Beissner, & Yacci, 1993) or cognitive structure (Shavelson, 1972). Taking in to consideration, in this study knowledge is presented to the students in the form of an integrated fabric.

7) Cognitive controls of problem solver

Individuals' cognitive styles and control represent patterns of thinking that control the ways that person process and reason about the information (Jonassen & Grabowski, 1993). Cognitive controls such as field independence, cognitive complexity, cognitive flexibility and category width are most likely to interact with problem solving (Davis & Haueisen, 1976; Heller, 1982; Maloney, 1981; Ronning, McCurdy, & Ballinger, 1984). Learners with higher cognitive flexibility and cognitive complexity should be better problem solvers than cognitive simplistic learners because they consider more alternatives and are more analytic (Stewin & Anderson, 1974).

8) Cognitive variables in problem solving

Research in science is seeking to bridge the gap between the cognitive structures of learners' science knowledge and their problem solving ability (Gabel & Bunce, 1994; Lee, 1985; Lee, Goh, Chia & Chin, 1996; Niaz, 1989a, 1989b, 1994). In this effort studies were done on the effect of various cognitive variables namely, working memory capacity, disembedding ability (degree of field dependence- independence), developmental level and the mobility-fixity dimension on problem solving (Johnstone, Hogg, & Ziane, 1993; Johnstone & Kellet, 1980; Niaz, 1988; Niaz & Logie, 1993; Tsaparlis

& Angelopoulos, 2000; Tsaparlis, Kousathana, & Niaz 1998) and found that these cognitive variables can be predictive of students' problem solving performance (Stamovlasis & Tsaparlis, 2005).

a) *Working memory capacity* : The concept of working memory that has been widely used in cognitive science refers to the human limited capacity system, which provides both information storage and processing functions (Atkinson & Shiffrin, 1968), and is necessary for complex cognitive tasks, such as learning, reasoning, language comprehension, and problem solving (Baddeley, 1986, 1990).

b) *Cognitive style/ disembedding ability*: Disembedding ability refers to the degree of field dependence/ field independence, and represents the ability of a subject to disembedd information in a variety of complex and misleading instructional context (Pascual- Leone, 1989; Witkin, Dyk, Paterson, Goodenough, & Karp, 1974). This ability is also connected with the ability of the subject to separate signal from noise.

c) *Developmental level*: Developmental level is a Piagetian concept and refers to the ability of the subject to use formal reasoning (Lawson, 1978,1985, 1993).

d) *The mobility- fixity dimension*: The mobility- fixity dimension is associated with the theories of Werner (1957), Witkin and Goodenough (1981) and Pascual- Leone (1989) and has been shown to be a good predictor variable in problem solving. According to Werner (1957), during individual development, perception is first global, i.e., field dependent (FD), and later analytical, i.e., field independent (FI), and finally in the mature individual synthetic, that is field mobile. The characteristics of subjects to function consistently in a FI fashion (i.e., fixity) and of others to vary that according to circumstances (i.e., mobility) has been referred to as the mobility-fixity dimension (Niaz, 1989b; Niaz & Saud De Nunez,1991; Niaz, Saud De Nunez, & Ruiz De Pineda, 2000; Stamovlasis, Kousathana, Angelopoulos, Tsaparlis, & Niaz, 2002; Witkin, 1965).

e) Cognitive flexibility: Cognitive flexibility or divergent thinking is the ability to bring multiple perspectives to the task at hand, and it is necessary for finding new solutions and creating new knowledge and tools (Ionescu, 2012).

9) Metacognition

Flavell (1979) described metacognition as the awareness of how one learns, the ability to judge the difficulty of a task, the monitoring of understanding, the use of information to achieve a goal, and the assessment of learning process. Metacognition is considered as the driving force in problem solving (Davidson & Sternberg, 1998; Gourgey, 1998; Lester, 1994; Masui & DeCorte, 1999).

Skill in metacognition and self regulation supports the development of mental models and the fidelity of external knowledge representations (Kim, 2012; Zimmerman & Campillo, 2003). Self regulation refers to the control learners have over setting goals, selecting appropriate learning strategies, maintaining motivation, and monitoring and evaluating academic progress (Ramdass & Zimmerman, 2011). Increasing metacognitive and self-regulated activities have shown to lead to higher recall and retention (Lee, Lim, & Grabowski, 2010; Poitras, Lajoie, & Hong, 2011) and deeper understanding (Bannert & Reimann, 2011) as learners become more aware of and take charge of forming their conceptualizations of problems.

In view of the importance of metacognitive strategies in problem solving, the present study incorporates various dimensions of metacognition in the instructional strategy, and it is one of the stated objectives of the study to examined effectiveness of Metacognitive Strategy Instruction on problem solving outcomes in Physics.

10) Epistemological beliefs

Epistemological beliefs are yet another internal factor that seems to effect problem solving. It refers to the learners' underlying beliefs about knowledge and how it develops. Learners' epistemic beliefs about the nature of problem solving affect the ways that they naturally tend to approach problems (Hofer & Pintrich, 1997).

11) Affective and conative factors

Solving problems, especially complex and ill-structured ones, requires significant affective and conative elements as well. Affective elements such as attitudes and beliefs about the problems, problem domain, and the learner's abilities to solve the problem significantly affect problem solving (Jonassen & Tessmer, 1996/1997). Conative elements such as engaging intentionally, exerting effort, persisting on task, and making choices also affect the effort that learners will make in trying to solve a problem (Mayer, 1998; Perkins, Hancock, Hobbs, Martin, & Simmons, 1986).

12) General problem solving skills

Some people are better problem solvers than others, because they use more effective problem solving strategies. Solvers who attempt to use weak strategies, such as general heuristics that can be applied across domains, generally fair no better than those who do not (Singley & Anderson, 1989). Whereas, solvers who use domain specific, strong strategies (Mayer &

Wittrock, 1996). Present study successfully attempted to teach novice problem solvers, domain specific metacognitive strategies for problem solving.

Problem solving is a complex cognitive skill mediated by metacognition. There can be numerous explicit and implicit factors affecting the process. Hence the factors presented here may not be comprehensive. Yet a sincere effort is made to summarize the various external and internal factors effecting problem solving in Table 1.

Table 1

External and Internal Factors Affecting Problem Solving

External Factors	**Internal Factors**
Problem Types	Familiarity
Well-structured/ Ill-structured	Domain and Structural Knowledge
Complex/ Simple	Cognitive controls
Domain Specific /Abstract Situated	Cognitive Variables
Problem Representations	Working Memory Capacity
Cognitive Tools	Disembedding Ability
Instruction	Developmental Level
	The Mobility-Fixity Dimension
	Cognitive Flexibility
	Representations
	Mental Models
	External Representations
	Metacognition
	Epistemological Beliefs
	Affective and Conative
	General Problem Solving Skills

Instructional Designs in Problem Solving

Problem solving plays a crucial role in science curriculum and instruction in most countries (Gabel & Bunce, 1994; Heyworth, 1999; Lorenzo, 2005). Improving students' problem solving skills continues to be a major goal of science teachers and science education researchers (Friege & Lind, 2006; Solaz- Portoles & Sanjose Lopez, 2007).

In most text books on instructional design, problem solving is not even mentioned. However, there are some works (Gagne, Briggs & Wager, 1992; Smith & Ragan, 1999; van Merrienboer, 1997) that deal with general problem solving strategies that focus on training complex cognitive skills that are required to solve problems. Unfortunately, problem solving requires more than the acquisition of pre-required skills (Mayer, 1998). Specific models of problem solving instruction needs to be proposed and tested (Jonassen, 2000).

Contemporary conceptions of student centered learning environments, like open-ended learning (Hannafin, Hall, Land, & Hill, 1994; Land & Hannafin, 1996), goal- based scenarios (Schank, Fano, Bell & Jona, 1993/1994), and even problem based learning (Barrows, 1985; Barrows & Tamblyn, 1980) focus on problem solving outcomes. They all recommend instructional strategies, such as authentic cases, simulations, modeling, coaching, and scaffolding to prop up inherent problem solving outcomes. Even then, they do not adequately explicate the nature of problems to be solved (Jonassen, 2000).

Instructional designs for well-structured problems are rooted in information processing theories, whereas instructional designs for ill-structured problems share assumptions with constructivism and situated cognition. Information processing theories conceive of learning outcomes as broad skills that can be applied across content domains, while constructivism and situated cognition argue for the domain specificity of any performance and call for instruction in some authentic context (Jonassen & Land, 2000).

Hausmann, Sande, and VanLehn (2007) proposed four types of instruction for problem solving viz., Prompting for self explanation, Example problem alternations, Step-based tutoring and Peer collaboration.

a) *Prompting for self explanation*: When teaching problem solving, instruction usually begins by presenting worked out examples. Student learner can be increased by prompting after each step to explain why that step is true, how it relates to what they know already, what is its role in solving the problem, etc…This method of prompting for self-explanation have shown to increase learning (Atkinson, Renkl, &Merrill, 2003; Chi, DeLeeuw, Chiu, & LaVancher, 1994; Hausmann & Chi, 2002; Taylor, O'Reilly, Sinclair, & McNamara, 2006).

b) *Example-problem alternations*: This is a type of problem solving instruction where students are told that once they have studied the example, it will be removed and they must solve a nearly identical problem. This method have shown to increase problem solving compared to either all-example or all-problem instruction (Atkinson, Derry, Renkl, & Wortham, 2000).

c) *Step-based tutoring*: This involves a human or computer tutor that allows the student to attempt each step in solving a problem, gives feedback on each step, gives a hint when asked (VanLehn, 2006). Many studies testify to their success compared to classroom instruction (Anderson, Corbett, Koedinger, & Pelletier, 1995; VanLehn, Lynch, Schultz, Shapiro, Shelby, Taylor., e.t.al., 2005). But students may misuse the feedback and hinds while using computer tutor by asking for so many hints that the system constantly gives away the correct steps or solution. This behavior is called gaming the system (Aleven, Stahl, Schworm, Fischer, & Wallace, 2003; Baker, Corbett, Koedinger, & Wagner, 2004). Step-based instruction of problem solving strategy can also be given in classrooms by a teacher. It includes the following steps (Selcuk & Caliskan, 2008).

1) Direct explanation: This involves explaining the problem solving process and strategies to raise student awareness of the purpose and rationale of strategy use,

2) Modeling: It is modeling of the strategies by the teacher (by thinking aloud),

3) Independent Practice: This gives students opportunities to practice the strategies which they are being taught,

4) Explicit Feedback: This provides frequent feed back to students on the quality and the strengths of their strategy using.

d) *Peer collaboration*: In the context of problem solving, peer collaboration refers to a small group of students working together to study an example or to solve a problem. Studies show that collaboration elicits more learning than individual (Johnson & Johnson, 1992; Slavin, 1990) collaboration may fail if one student does most of the work while others do little. This is called social loafing, domination or both (O’Donnell & Dansereau, 1992). Collaboration may also fail due to floundering, where the students are on the task and even collaborating, but are making little progress (Barron, 2003).

Though present study choose solution of well-structured problems, it share the assumptions of constructivism and situated cognition, that different kinds of problem solving in different contexts and domains summon different skills. This research develops a task-specific instructional strategy focusing on different component skills to support the learning of domain specific problem solving.

Knowledge Domain in Problem solving: Role of Concept Maps

Knowledge and competence are in a cause-effect relationship. On the one hand knowledge is the precondition to solve certain problems, and problem solving indicates competence. On the other hand, knowledge might also be enlarged by solving a new problem, i.e., new knowledge is being acquired (Friege & Lind, 2006). Therefore it is essential to consider knowledge acquisition and the type of knowledge that facilitate problem solving.

The development of knowledge base is important both in terms of its extent and its structural organization (Solaz-Portoles & Sanjose Lopez, 2007). The knowledge needed to solve problems in a complex domain like physics is composed of many principles, examples, technical details, generalizations, heuristics, and other pieces of relevant information (Stevens & Palacio-Cayetano, 2003). Any claim that knowledge can always be found from other sources when it is needed, is naive (Dawson, 1993).

Over decades, different researchers proposed different types of knowledge involved in problem solving in science. Table 2 presents an overview of various types of knowledge entailed in problem solving as recommended by various researchers.

Table 2

Types of Knowledge Involved in Scientific Problem Solving

Proposers	Types of Knowledge Involved in Scientific Problem Solving
Anderson (1980)	1. Factual or declarative knowledge 2. Reasoning or procedural knowledge 3. Regulatory or metacognitive knowledge
Ferguson-Hessler & de Jong (1990)	1. Situational Knowledge (knowledge of problem situations that enables the problem solver to shift relevant features out of the problem statement) 2. Declarative knowledge (conceptual knowledge that involves facts and principles that apply within a certain domain) 3. Procedural Knowledge (knowledge of actions or manipulations that are valid within a domain) 4. Strategic knowledge (knowledge that help the student to organize the problem solving processes into stages he/she should go through in order to reach a solution)
de Jong & Ferguson-Hessler (1996)	1. Hierarchical organization of knowledge (superficial/ deeply embedded) 2. Inner structure (isolated knowledge elements/ well structured, interlinked knowledge) 3. Level of automation (declarative /compiled) 4. Level of abstraction (colloquial/formal)
O’Neil & Schacter (1999)	1. Content knowledge 2. Problem solving strategies 3. Metacognition
Shavelson, Ruiz-Primo, & Wiley (2005)	1. Declarative knowledge (domain specific content: facts, definitions, and descriptions) 2. Procedural knowledge (production rules/ sequences) 3. Schematic knowledge (principles/schemes) 4. Strategic knowledge (when, where and how knowledge applies, strategies/ domain specific heuristics)
Friege & Lind (2006)	1. Conceptual knowledge 2. Problem scheme knowledge

Researchers also demonstrates different means to measure declarative knowledge, procedural knowledge, and strategic knowledge. Concept and cognitive maps provide valid evidence of conceptual structure of declarative knowledge (Ruiz-Primo & Shavelson, 1996a). Performance assessments are needed to measure procedural knowledge (Ruiz-Primo & Shavelson, 1996b). Strategic knowledge is rarely directly measured. It is rather implied whenever other types of knowledge are measured (Shavelson, Ruiz-Primo, & Wiley, 2005).

Concept maps and diagrams along with a notebook tool can provide a visual medium for helping learners to notice what they know from what they need to find out (Henning, 2004; Kozma, 2003). Flexible representation tools can also offer insight in to how a student is thinking about the problem and where critical concepts remain unformed (Kim, 2012).

It is often found that students often do not succeed in applying knowledge which they have acquired in lessons to solve problems given in school or in everyday life contexts (Friege & Lind, 2006). This may be due to lack of proper organization of knowledge and ignorance of problem scheme knowledge. Less is known about how knowledge which is relevant for problem solving should be organized in a domain as rich in content as physics (Kintsch & Ericsson, 1996).

Role of concept maps in learning and problem solving

Before proceeding to discuss the role of concept maps in problem solving, it will be helpfull to describe what are concept maps and provide a theoretical framework supporting their uses, the steps followed while developing a concept map and the challenges involved in using concept maps.

Concept maps were first developed by Novak and Gowin (1984). It is a graphical tool for organizing and representing knowledge. It is based on Ausubel's (1968, 2000) assimilation theory of learning. According to Novak and Gowin (1984) a concept map is a schematic device for representing a set of concept meanings embedded in a framework of propositions. Using a concept map one can think and learn with concepts by linking new concepts to what one already know (Canas, Coffey, Carnot, Feltovich, Hoffman, Feltovich, & Novak, 2003). Learning with concept maps means that the learner is making an intentional effort to link, differentiate and relate concepts to one another. In a concept map concepts are stored hierarchically and get differentiated as learning grows (Irvine, 1995; Nowak & Gowin, 1984).

Theoretical framework of concept maps

According to Ausubel and his co-workwers during the process of thinking and learning with concepts, an individual uses three processes: subsumption, progressive differentiation and integrative reconciliation (Ausubel, 2000; Ausubel, Novak, & Hanesian, 1986). In subsumption, lower-order concepts are subsumed under higher-order concepts (Pinto & Zeitz, 1997). Progressive differentiation is similar to the process of analysis and involves breaking down of concepts in to finer and finer components. Integrative reconciliation is similar to the process of synthesis and occurs when the learner attempts to reconcile and link concepts on one side of the map with concepts on other side (Boxtel, Linden, Roelofs, & Erkens, 2002; West, Park, Pomeroy, & Sandoval, 2002).

Developing concept maps

Developing a concept map necessitates the learner to engage in an active process consisting of the following steps.

Step 1: Identifying the most general concepts and placing them at the top of the concept map.

Step 2: Identifying more specific concepts that relate to the general concepts in some way.

Step 3: Tying together the general and specific concepts with linking words that make sense.

Step 4: Looking for cross-linkages that tie the concepts from one side of the map to concepts of the other.

Concept maps can either be created by hand with paper and pencil, or by using one of many computer-based software programs, like CMap tools.

Challenges in using concept maps

- It takes time for students and teachers to understand and incorporate concept maps as learning and teaching strategy as it is new to them.
- Concept maps necessitate the shift of teachers' focus from lecturing contents to the design of concept maps and students' meaningful understanding of concepts.
- Concept maps on the same topic developed by two different experts will look different as they reflect the cognitive structures of different people.

Metacognitive Strategies in Problem Solving

A metacognitive strategy is a systematic cognitive technique to assist students in recognizing, planning, implementing and monitoring solutions to problems (Dirkes, 1985). The basic metacognitive strategies are:

- Connecting new information to former knowledge.
- Selecting thinking strategies deliberately.
- Planning, monitoring, and evaluating thinking processes.

Several researchers consider metacognitive strategies as having a vital role in aiding problem solving. Before describing the role of metacognitive strategies in problem solving, let us discuss what is metacognition?, what are its constituent elements, how metacognition develops through ages and what prime factors should we consider while teaching metacognition.

Defining metacognition

Flavell while coined the word ‘metacognition’, defined it in simple words as ‘thinking about thinking’. According to him, metacognition refers to knowledge of one’s own cognitive processes, i.e., knowledge of how one monitors cognitive processes and how one regulates these processes (Flavell, 1976). Over the decades, various definitions of metacognition have developed that include considerations of both cognitive and metacognitive processes, and a numerous labels have been used like metacognitive knowledge, metacognitive awareness, metacognitive skills, and metacognitive beliefs (Veenman, Van Hout-Wolters, & Afflerbach, 2006). A few definitions given by psychologists and educationists are presented in Table 3.

Table 3

Definitions of Metacognition

Proposal	Definitions
Flavell,1979, p.906	Thinking about thinking
Cross and Paris, 1988,p.131	The knowledge and control children have over their own thinking and learning activities.
Hennessey, 1999, p.3	Awareness of one's own thinking, awareness of content of one's conceptions, an active monitoring of one's cognitive processes, an attempt to regulate one's cognitive processes in relation to further learning and an application of a set of heuristics as an effective device for helping people organize their methods of attack on problems in general.
Kuhn and Dean, 2004, p.270	Awareness and management of one's own thought that enables a student who has been taught a particular strategy in a particular problem context to retrieve and deploy that strategy in a similar but new context.
Martinez, 2006,p.696	The monitoring and control of thought.

These definitions show that metacognition focuses on thinking process. It is concerned with the knowledge, monitoring and control of persons' thinking to achieve specified goals.

Overlap among critical thinking, metacognition and self-regulation

Certain terms like critical thinking and self regulation are often considered synonymous with metacognition. Martinez (2006) argues that critical thinking can be subsumed under metacognition, because most skills of critical thinking overlap component skills of metacognition like analyzing arguments (Ennis, 1985; Facione, 1990; Halpern, 1998; Paul, 1992), making inference using inductive or deductive reasoning (Ennis, 1985; Facione, 1990; Paul, 1992; Willingham, 2007), judging or evaluating (Case, 2005; Ennis, 1985; Facione, 1990; Lipmann, 1988; Tindal & Nolet, 1995), and making decisions or solving problems (Ennis, 1985; Halpern, 1998; Willingham, 2007).

Veenman, Van Hout-Wolters, and Afflerbach (2006) noted that some theorist view self-regulation to be a subordinate component of metacognition (Brown & DeLoache, 1978), whereas others regard self-regulation as a super ordinate to metacognition (Muis, 2007; Winne & Hadwin, 1998). Several theorists regard metacognition as the hub of self-regulation (Borkowski, Chan, & Muthukrishna, 2000; Lefebvre-Pinard & Pinard, 1985; Muis, 20007; Paris & Winograd, 1990; Winne & Hadwin, 1998). They described how metacognition can facilitate or constrain facets of self-regulated learning, and propose that metacognition is one key moderator of performance (Lefebvre-Pinard & Pinard, 1985; Paris & Winogard, 1990).

Schraw, Crippen, and Hartley (2006) argue that both metacognition and critical thinking are subsumed under self-regulated learning, which is our ability to understand and control our learning environments. Self regulated learning refers to metacognition, motivation and cognition and includes critical thinking.

It can be concluded that metacognition supports critical thinking and self-regulation makes it more likely that one will engage in high-quality critical thinking.

Constituent elements of metacognition

Metacognition involves two major constituents' viz., knowledge about cognition and monitoring of cognition. There are several frameworks for categorizing types of knowledge about cognition and ways of monitoring of cognition. These frame works were developed by different researchers (Cross & Paris, 1988; Flavell, 1979; Paris & Winogard, 1990; Schraw & Moshman, 1995; Schrew, Crippen, & Hartely, 2006; Whitebread, Coltman, Pasternak, Sangster, Grau, Bingham, Almeqdad, & Demetriou, 2009). Figure 1 gives a summary of the categorization of constituent elements of metacognition.

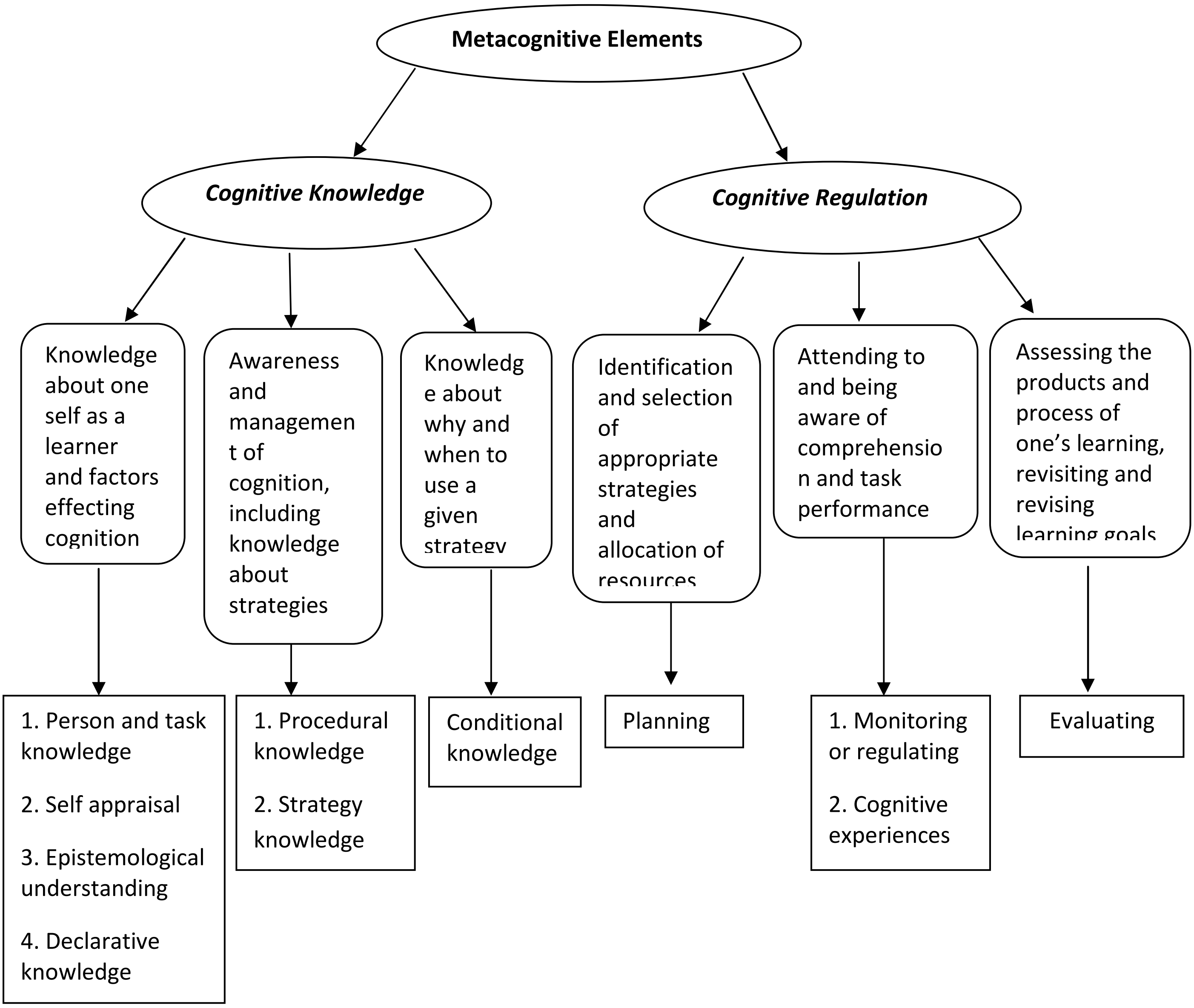


Figure 1: Categorization of Constituent Elements of Metacognition

Schraw and Moshman (1995) describes there are three types of metacognitive theories that integrate cognitive knowledge and cognitive regulation. They are tactic theories, informal theories and formal theories.

Tactic theories are developed without explicit awareness from personal experiences or interactions from peer. In informal theories individuals may be aware of some aspects of these theories, but lack an explicit structure for organizing their beliefs about knowledge. Formal theories are highly systematic and structured and are subjected to purposeful and rigorous evaluation.

Development of metacognition

Studies on the development of metacognition show that it is a late developing skill (Flavell, 1979; Schraw & Moshman, 1995; Whitebread e.t.al., 2009). Children typically do not develop metacognitive skills before 8-10 years (Whitebread e.t.al., 2009).

Schraw and Moshman (1995) observed that young children below ten years of age have difficulty in monitoring their thinking during task performance and in constructing metacognitive frameworks that integrate cognitive knowledge and cognitive regulation. They observed that metacognitive skills like planning, selecting appropriate strategies, and allocating relevant resources do not appear until 10-14 years of age.

Kuhn (2000) identifies metacognition as a very gradual, multidirectional movement to acquire better cognitive strategies to replace inefficient ones. Many researchers have concluded that metacognitive abilities appear to improve with age (Cross & Paris, 1988; Hennessey, 1999; Kuhn & Dean, 2004; Schneider, 2008; Schneider & Lockl, 2002; Schraw & Moshman, 1995).

Schraw and Moshman (1995) proposed a developmental procedure for metacognition. According to them cognitive knowledge appears first at the age of 6 and gets consolidated and evident by 8-10 years of age. Ability to regulate cognition and improvements in monitoring appears by 10-14 years of age in the form of planning. Monitoring and evaluation are slower to develop and they may be incomplete even in adults.

Kuhn and Dean (2004) displayed epistemological understanding as a benchmark in the development of metacognition. According to this framework preschool children believes that everyone perceives the same thing, and all perceptions match external reality. By the age of four they reach the stage of absolutism, where they learn that two people believes can differ, but one person is right and other person is wrong. By adolescence they reach the stage of multiplism or complete relativism, realizing no beliefs can be judged, and opinions can be equally right. By adulthood, people learn to support opinion with reason and evidence and make evaluation.

Metacognitive Activities/Skills

Relation of metacognition with learning results is the subject of many educational studies. Even then, it is by no means clear which particular metacognitive activities are related to learning results. Identifying these activities related to learning outcomes can render suggestions for metacognitive training (Sperling, Howard, Miller, & Murphy, 2002; Veenman, Elshout, & Meijer, 1997; Wang, Haertel, & Walberg, 1990)

Metacognitive activity can be distinguished at various levels of specificity (Van Hout-Wolters, Simons, & Volet, 2000). At the highest levels, components such as planning, monitoring and evaluation can be distinguished. At intermediate level, more specific components such as selection of information, recapitulation and reflection on learning process can be discriminated. At the lowest level, metacognitive activity is defined at task level, like inferring the meaning of an unknown word from its context, examining a special case of a problem and modifying a problem etc… (Pressley, 2000; Schoenfeld, 1987)

In addition to this several educationalists have identified and distinguished several sets of metacognitive activities or skills. These metacognitive skills or activities distinguished by educationalists over decades are summarized in Table 4

Table 4

Summary of Metacognitive Skills/ Activities Identified from Review

Proposal	Metacognitive Activities
Flavell (1979) Schraw and Moshman (1995)	1. Planning (before commencing a task) 2. Monitoring (during execution of the task) 3. Evaluation (up on completion of the task)
Lester and Garofalo (1982)	1. Orientation, 2. Organization, 3. Execution, 4. Verification
Brown, Bransford, Ferrara, & Campione ((1983)	1. Planning,2. Monitoring, 3. Goal appropriate behavior
O'Neil & Abedi (1996) Pintrich & De Groot (1990)	1. Planning, 2. Monitoring, 3. Cognitive Strategies, 4. Awareness
Schoenfeld (1992, 1987)	1. Analysis, 2. Exploration, 3. Verification
Veenman (1993) Veenman, Elshout, & Meijer (1997)	1. Orientation (preceding planning) 2. Systematic orderliness (including planning) 3. Evaluation (including monitoring)
Schraw, & Dennison (1994)	1. Metacognitive knowledge (declarative knowledge, procedural knowledge, conditional knowledge) 2. Metacognitive regulation (Planning, information management, monitoring, debugging, and evaluation)
Alexander, Carr, & Schwanenflugel (1995)	1. Declarative metacognitive knowledge, 2. Cognitive monitoring, 3. strategy regulation and control
Nelson (1996) Winne (1996)	1. Metacognitive monitoring (flow of information from the object level to the metacognitive level) 2. Metacognitive control (flow of information from metacognitive level to the object level)
Hattie, Biggs, & Purdie (1996)	1. Planning, 2. Implementing, 3. Monitoring learning efforts, 4. Conditional knowledge and use of tactics and strategies
Butler (1998)	1. Task Analysis, 2. Interpreting task requirements, 3. Goal-setting, 4. Selection, 5. Adaptation 6. Invention of appropriate strategies, 7. Monitoring of progress, 8. Generation of internal feed back 9. Adjustment of learning approaches 10. Use of motivational and volition-control strategies
Pintrich, Wolters, & Baxter (2000)	1. Metacognitive knowledge 2. Metacognitive judgments and monitoring 3. Self regulation and control
Desoete, Roeyers. Buysse, & De Clercq (2002)	1. Prediction, 2. Evaluation

Though different authors present different nomenclatures for metacognitive skills/ activities, there are similarities in these manifold components of metacognition. It can be seen that planning or orientation, implementation or strategy use, and evaluation or verification are common in most of these metacognitive skills. Since the study instructs and assesses metacognitive strategy use in problem solving context, and since representing a problem decide successful problem solving as observed in various studies on problem solving, it considers

(i) Representing a problem,
(ii) Planning for a solution,
(iii) Implementing the plan, and
(iv) Evaluating the solution

as component skills in a metacognitive strategy of problem solving.

Further Veenman, Prins, and Verheiji (2003) opined that it is better to assess metacognitive activities when persons execute a task than by means of questionnaires. Many researchers also observed that metacognitive activities are not usually task specific. They are generalisable across tasks and domains (Schraw, Dunkle, Bendixen, & Roedel, 1995; Veenman, Elshout, & Meijer, 1997; Veenman & Verheiji, 2001; Veenman, Wilhelm, & Beishuizen, 2004)

Teaching metacognition

Several researchers offer evidence that metacognition is teachable (Cross & Paris, 1988; Haller, Child, & Walberg, 1988; Hennessey, 1999; Kramarski & Mevarech, 2003). Researchers recommend a number of specific instructional approaches to teaching metacognition. Cross and Paris (1988) recommended providing explicit instruction in declarative, procedural and conditional knowledge as part of instruction. Schraw, Crippen, and Hartley (2006) and Schraw (1998) urge teachers to provide explicit instruction in cognitive and metacognitive strategies. Schraw (1998) also suggest that such instruction should emphasize how to use strategies, when to use them, and why they are beneficial.

Schraw (1998) advocate providing explicit prompts to help students improving their regulating abilities. He recommended using a checklist with entries for planning monitoring and evaluation with sub-questions included under each entry that need to be addressed during the course of instruction. He suggested that such a check list help students to be more systematic and strategic during problem solving.

Researchers further recommended the use of collaborative or co-operative learning structures for encouraging development of metacognitive skills (Cross & Paris, 1988; Hennessey, 1999; Kramarski & Mevarsch, 2003; Kuhn & Dean, 2004; Martinez, 2006; McLeod, 1997; Paris & Winograd, 1990; Schraw & Moshman, 1995; Schraw, Crippen, & Hartley, 2006). These suggestions are rooted in Piagetian and Vygotskyian tradition that highlights the potential for cognitive improvement when students interact with one another.

Schraw and Moshman (1995) noted that peer interaction can encourage the construction and refinement of metacognitive theories that are frameworks for integrating cognitive knowledge and cognitive regulation. Kuhn and Dean (2004) suggested that social discourse can cause students to internalize processes of providing elaborations and explanations, which have been associated with improved learning outcomes.

Researchers also emphasize that instructors should promote general awareness of metacognition by modeling metacognitive skills during instruction (Kramarski & Mevarech, 2003; Martinez, 2006; Schraw, 1998)

Role of metacognition in problem solving

Successful problem solving depends on three components viz., skill, meta-skill and will. Each of these components can be influenced by instruction. When the instruction aims at promoting non-routine problem solving, students should possess the relevant skill, meta-skill and will. Meta-skill in the form of metacognition is central in problem solving because it manages and co-ordinates the other components (Mayer, 1998).

While solving an analogy problem, a problem solver needs to engage in the cognitive processes of encoding, inferring, applying, and responding. Training in componential skills, especially inferring and applying improve students' problem solving performance (Robins & Mayer, 1993). However, expertise in executing the component processes is not sufficient for problem solving transfer. Based on a series of studies, Sternberg (1985) suggests mastering each component skill is not enough to promote complex problem solving. Students must know not only what to do, but also when to do it. Therefore on the development of learning strategies special focus should be given to controlling and monitoring cognitive processes (Pressley, 1990). This aspect of problem-solving ability is called problem solvers' meta-skill.

Meta-skill or metacognition which seems to be an important component in problem solving involves knowledge of when to use, how to coordinate, and how to monitor various skills in problem solving (Mayer, 1998). A meta-skill based approach further suggests modeling of how and when to use strategies in realistic academic tasks.

Collaborative Problem Solving

Group discussions emerged as a common pedagogical practice in science during 1970s and 1980s as a result of a movement towards student centered learning and constructivist approach, where it is considered important to give students opportunities to articulate and reflect upon their own ideas about science (Bennett, Lubben, Hogarth, & Campbell, 2004).

Peer interaction or collaborative group discussion as a teaching-learning technique seems to effect cognitive and metacognitive development of students. Researchers examining the relation between peer social interaction and cognitive development have usually been based on the theories of either Piaget or Vygotsky (Tudge, 1992).

Piaget (1959) proposed that a child’s cognitive development depended upon manipulation of, and active interaction with, the environment. Central to the learning process according to him are the states of disequilibrium due to an imbalance between what is understood and what is encountered. Piaget suggested that peer interaction promoted cognitive conflict by exposing discrepancies between the peers’ own and others knowledge, resulting in disequilibrium. As higher levels of understanding emerge, through dialogue and discussions with individuals of equal status, equilibrium is restored and simultaneously cognitive change occurs. This is regarded as an internal process, which then manifests itself in behavior (an “inside-out” theory; Garton, 2004). Studies grounded on a Piagetian constructivist framework have largely supported this view that working with a peer leads to greater cognitive benefit than working alone (Dimant & Bearison, 1991; Druyan, 2001; Golbeck & Sinagra, 2000; Kruger, 1992).

According to Vygotsky (1978) learners should be guided or scaffolded by a “more capable peer” to solve a problem or carry out a task that would be beyond what they could accomplish independently. In contrast to Piagetian theory, there is an external process, co-constructed by the sharing of knowledge which is then internalized discussed as an ‘outside-in’ theory; (Garton, 2004). Within this perspective there are two key concepts: zone of proximal development and inter-subjectivity (Vygotsky, 1978). The zone of proximal development is the difference between what a child can accomplish independently and what can be achieved in conjunction with a more expert partner. Inter-subjectivity is the shared understanding that results from individuals discussing their differing viewpoints. The expert is viewed as having responsibility for adjusting the level of support or guidance required (scaffolding) to fit the ‘novices’ zone of proximal development. Studies grounded in a Vygotskian framework have supported the view that cognitive development depends on active social interaction, including reasoning and explanation, with a more competent partner who has a different subjective understanding of the tasks (Garton & Pratt, 2001; Samaha & De Lisi, 2000; Tudge, Winterhoff, & Hogan, 1996).

Over the years, collaborating learning have gained popularity (Biggs, 2003) with associated research that provided concrete recommendations about group size or construction of assignments to optimize student learning (Heller & Hollabaugh, 1992). It has been argued that group work enhances the quality of education by helping the students to develop a deep approach to learning (Jaques, 2000; Ramsden, 1992).

Further, meta-analysis show that small group has positive effect on students academic achievement, persistence and attitudes (Lou, Abrami, & d'Apollonia, 2001; Springer, Stanne, & Dnovan, 1999)

Berge and Danielsson (2012) observed that the interaction between group members as they solve physics problems were primarily executed through speech, drawings and writing of equations. Even if most students know which metacognitive strategies are good and witch are bad, they do not always apply the metacognitive strategies that the instruction invites. But when they work in pairs they are more likely to use the good strategies because social accountability improves metacognitive strategy choice, which thereby improves learning and problem solving. Further while making meta-cognitive strategy choices public may embarrass students who choose a bad meta-cognitive strategy. To avoid embarrassment, they may choose good meta-cognitive strategies more frequently and thus learn more effectively (Hausmann, Sande, & VaLehn, 2007).

Studies on Problem Solving, Metacognition and Concept Maping

This section presents a brief review of studies conducted on problem solving, metacognition, concept mapping and peer interaction during the period 1978-2014. This is divided in to sub-sections dealing with studies on problem solving, metacognitive strategies in problem solving, collaborative problem solving, and nature of knowledge domain needed for problem solving. Separate consideration is given to Indian studies on problem solving and metacognition.

Studies on Problem Solving in Academic Contexts

A review of studies conducted on problem solving are presented in this section. Special focus is given to studies on problem solving in physics though some studies on problem solving in general and in other domains like mathematics and chemistry are included. Few studies on concept attainment in physics are included keeping in mind its predictive role in physics problem solving. A sub-section on Indian studies on problem solving is described separately.

Bigozzi, Tarchi, Falsini, and Fiorentini (2014) compared a progressive-learning approach to physics, based on knowledge building pedagogy, to a content centered approach in which explanations, experiments and discussions are centered on the transmission of knowledge. Forty- six students attending the first year of high school participated in their study over a whole school year. Students' knowledge and mastery of physics concepts were assessed through questionnaires containing both open-ended and multiple-choice questions. Overall, the progressive-learning group outperformed the content-centered group. Based on their study, researchers concluded that the teaching of physics should be slow, cyclic, and developmentally appropriate for the context.

Kosem and Ozdemir (2014) described the possible variations of thought experiments in terms of their nature, purpose, and reasoning resources adopted during the solution of conceptual problems. High school level conceptual problems related to fundamental physics laws on mechanics were used in the study. Three groups of participants with varying levels of physics knowledge- low, medium, and high- were selected in order to capture potential variations. Graduate students majoring in physics and students who have already passed the PhD qualifying exam were taken as the high level group. Undergraduate students who had been attending the Department of Physics Education for four semesters comprised the medium level group. 12^{th} grade students in a high school comprised the low level group. Five participants were selected within each level group and the study was conducted with fifteen participants in total. Think aloud and retrospective questioning strategies were used throughout the individually conducted problem solving sessions to capture variations in the participants' thinking process. The analysis of data showed that thought experiments were actively used cognitive tools by participants from all three levels while working on the problems. Researchers also observed that participants conducted thought experiments for different purposes such as prediction, proof and explanation. The reasoning resources behind the thought experimentation processes were classified in terms of observed facts, intuitive principles, and scientific concepts. After the study researchers argued that instructional practices enriched with thought experiments and related practices not only reveal hidden elements of students' reasoning but also provide students opportunities to advance their inquiry skills.

Mellingsaeter and Bungum (2014) presented a case study of how the Interactive White Board (IWB) may facilitate collective meaning making processes in group work in engineering education. First year students of a Norwegian university college students attended group work sessions as an organized part of a basic physics course. Each student group was equipped with an IWB, which they used to write down and hand in their solutions to physics problems. Researchers investigated how the students used the IWB in the group work situation. From qualitative analysis of video data, they identified four group work processes where the IWB played a key role, viz., exploratory, explanatory, clarifying and insertion. The results revealed that the IWB may facilitate a 'joint workspace' for students' physic problem solving.

Susac, Bubic, Kaponja, Planinc, and Palmoric (2014) studied how eye movements reveal student strategies in solving equations, which is an important skill required for problem solving. Researchers recognized eye movements of 40 university students while they were rearranging simple algebraic equations. The participants also reported on their strategies during equation solving in a separate questionnaire. The analysis of the behavioral and eye tracking data, namely the accuracy, reaction time, and the number of fixations revealed that the participants improved their performance during the time course of their measurement. The results indicated that the number of fixations represents a reliable and valuable measure that can give insights in to participants' flow of attention and efficiency in equation solving. The comparison of eye movement data and questionnaire reports were used for measuring the validity of participants' metacognitive insights. The measure derived from eye movement data was found to be more objective and reliable than the participants' report, indicating that the measurement of eye movements provides insights in to unavailable cognitive processes and may be used for exploring problem difficulty, student expertise, and metacognitive processes.

Bogard, Liu, and chiang (2013) conducted a multiple case study that examined how advanced learners solve complex problems. They focused on how their application of cognitive processes contributed to difference in performance outcomes. They found that mastering problem solving operations within each threshold of knowledge development enhanced learners, conceptual awareness of where to apply cognitive processes and increased the combination of cognitive processes they activated at higher thresholds.

Carlgren (2013) in her article ‘communication, critical thinking, problem solving: A suggested course for all high school students in the 21st century’ argued that current high school students are hindered in their learning of communication, critical thinking, and problem solving. She claims that the hindrances are due to three factors viz., the structure of the current education system, the complexity of the skills themselves, and the competence of the teachers to teach these skills in conjunction with their course material. She further advocated that all current high school students need the opportunity to develop these skills and that a course be offered to explicitly teach students these skills within a slightly modified western model of education.

Coelho (2013) investigated whether problem solving could be improved by means of HPS (History and Philosophy of Science). Three typical problems from introductory courses of mechanics, viz., the inclined plane, the simple pendulum and the Atwood machine were taken as the object of the study. The solving strategies of these problems in the 18th and 19th century constructed the historical component of the study. Its philosophical components stemmed from the foundations of mechanics research literature. The researcher found that traditional solving strategies for the incline and pendulum problems are adequate for some situations but not in general. The investigator suggested that development of logical thinking by means of the variety of lines of thoughts provided by HPS is essential.

Lee and Park (2013) developed a deductive explanation task (DET), using Hempel's deductive-normative model for scientific explanation. They applied this task in teaching students to improve their knowledge about force and motion. Their study consisted of two steps: the preliminary study and the main study. Preliminary study was conducted to explore the conditions for the successful application of the developed learning materials to other classes and investigated the students' conceptual change by comparing their pre-test and post-test scores. The effectiveness of the DETs were checked by comparing the scores of students who used the DETs with the scores of students who did not. In the preliminary study, 7 classes with 269 tenth grade male students participated. In the main study, two classes with 64 students from the 11^{th} grade participated. In addition 72 students from 11^{th} grade participated as a control group. The results showed that many students received benefits and reached a good conceptual understanding by using the DET. Also, students responded that learning physics through deductive thinking was less difficult, and the method of learning was interesting.

Safadi and Yerushalmi (2013) examined the impact of troubleshooting (TS) and problem solving (PS) tasks on student's conceptual understanding. The study was conducted in two sixth-grade classes taught by the same teacher, in six lessons that constituted one third of a unit on simple electronic circuits. In those lessons, one class was assigned PS lessons where students were asked to solve conceptual problems. Later they were asked to share their work in a class discussion. The other class was assigned TS lessons where students were asked to identify, explain, and correct the mistakes in teacher made erroneous solutions to the same problems. They were also engaged in a class discussion. Researchers found that students' performance on subsequent transfer problems was significantly higher to the TS class, in particular for students with low prior knowledge.

Stadler and Garcia (2013) analyzed the results of an educational experience using the problem based learning (PBL) method in physics course for undergraduates enrolled in the technical telecommunication engineering degree program. PBL included problem solving activities and instructors guidance to facilitate learning. It involves posing a 'concrete problem' to initiate the learning processes implemented by small groups of students. From an instructor's perspective, PBL strengths include better student attitude in class and increased instructor-student and student-student interactions. The students emphasized developing team work and communication skills in a good learning atmosphere as positive aspects. Researchers advocate that active learning methods can be appropriate in engineering, as their methodology promotes metacognition, independent learning and problem solving skills.

Bacerra-Labra, Gras-Marti, and Torregrosa (2012) proposed a model of teaching/ learning based on a 'problem based structure' of the contents of the course, in combination with a training in paper and pencil problem solving that emphasizes discussion and quantitative analysis rather than formula plug in. the researchers aimed to reverse the high failure and attrition rate among engineering undergraduates taking physics. A number of tests and questionnaires were administered to a group of students following a traditional lecture based instruction, as well as to another group following an instruction scheme based on the proposed approach. The results showed that the students who followed the new method could develop scientific reasoning habits in problem solving skills, and show gains in conceptual learning, attitudes and interests, and the effects of the approach on learning where noticeable several months after the course.

Berge and Danielsson (2012) explored how a group of four university physics students addressed mechanics problems, in terms of student direction of attention, problem solving strategies and their establishment of the ways of interacting. Data of the study included video tapes of students working collaborate on physics problems and interviews with students and tutor. After analysis, researchers suggested that teachers need to scaffold conceptual discussions when participating in the groups, as students may have strong preconceptions about not only the physics content but also about problem solving strategies. They argue that physics students would benefit from the inclusion of meta-cognitive discussions about problem solving practices.

Hong, Chen, Wong, Hsu, and Peg (2012) analyzed the physics concepts employed by the students as they completed hands on project named “Crawling Worm”. College students were required to design a crawling worm using planning, self-monitoring, and self evaluation processes to solve contradictive problems. Based on the analysis of participants’ working portfolios and by reviews and interviews by engineering professors, the results of the study showed that the crawling worm design competition encouraged the practice of problem solving and it facilitated the learning of physics concepts such as friction, torque, four bar link, material properties and so on. The researchers also advocated that to enhance the efficiency of problem solving, one needs to practice metacognition based on an application of related scientific concepts.

Kim (2012) proposed a stage-sequential model of learning progress by measuring the surface, structure and semantic features of external representations. He named the learner through different stages of knowledge development as novice, advanced beginner, competent learner, proficient learner, and intuitive experts. He found that mental models as assessed through external representations become more integrated and conceptually complex as the learner progress through these stages.

Shiakalli and Zacharos (2012) studied whether problem solving can be taught in early education and whether appropriate teaching interventions can be developed to scaffold children's efforts to solve problems. 18 public pre-school children in Cyprus constituted the sample. The researchers asked these children to find all solutions of the pentomino. The children's problem solving was supported by graphically representing their solutions on squared paper. The findings showed that children responded positively to the problem and were successful in finding all solutions for the specific problem. The graphical representations of the solutions and the forms of teacher-children and children-children interactions played an important role in the positive outcome of the activity.

Uhden, Karam, Pietrocola, and Pospiech (2012) in their paper entitled 'Modeling Mathematical Reasoning in Physics Education' reveal the strong conceptual relationship between mathematics and physics. They opine that the role of mathematic in physics has multiple aspects: (1) Pragmatic perspective (its serves as a tool), (2) Communicative function (it acts as language), and (3) Structural function (it provides away of logical deductive reasoning). According to the authors, what is needed in the progress of physics teaching is not meaningless calculations, but conceptual translations of physical ideas in to mathematical language. In addition mathematics can reveal new insights in the understanding of physics. Therefore teaching strategies in physics should focus on the structural role of mathematics.

Waller and Kaye (2012) designed and executed a three months course in problem solving, modeling and simulation for nuclear engineering students. They adopted a collaborative approach and were undertaken with instructors from both industry and academia. Training was optimized for the laptop based pedagogy that included modeling and simulation components. The concepts and tools learned as part of the training were observed to be utilized throughout the duration of student university studies. Interview with students who entered the workforce later, indicated that the approaches learned and practiced were retained long term.

Pathak, Kim, Jacobson, and Zhang (2011) conducted a qualitative study examining the problem solving dynamics of two dyads: a Productive Failure (PF) dyad who initially received a low structured activity and a Non-Productive Failure (NPF) dyad who initially received a high-structured activity. Both dyads then received a high-structured problem solving activity. The participants in the study were grade 10 students who were studying for their General Cambridge ‘O’ Level Examination in an all-boys school in Singapore. The researcher recorded the computer screen activities and conversations of six PF and six NPF on two topics (Ohm’s Law and Parallel Circuit) amounting to 160 minutes of problem solving activities. Data of the study included video conversations of the dyads, screen captures of their use of a computer model, and their submitted answers. Results of the study indicated that initial struggle and failed attempts provided an opportunity to the PF dyad to expand their observation space and thus engage deeply with the computer model compared to the NPF dyad.

Spector (2010) suggested that development of mental model is typically made known through examining external knowledge representations. He opined that it is what the person is thinking and how that person is thinking about the problem situation that is very strongly correlated with the quality of the solution that is developed and implemented. He also suggested that research is needed to examine how reliably do configurations of tool use patterns, solution operations and cognitive processes serve as an index for mental model development.

Alibali, Phillips, and Fischer (2009) conducted studies on expert-novice differences in problem solving. They suggest that self-regulation is improved as mental models grow to include procedural knowledge of strategies. They observed that learning a problem solving strategy can lead to better problem representations, and problem representations can lead to better use of strategies.

Pol, Harskamp, Suhre, and Geodhart (2008) investigated whether physhint program (a student controlled computer program that supports students in developing their strategic knowledge in combination with support at the level of content knowledge) succeeds in improving strategic knowledge by allowing for more effective practice time for the student (practice effect) and/ or by focusing on the systematic use of the available help (systematic hint use effect). Analysis of qualitative data from the experimental study conducted among secondary students showed that both the expected effectiveness of practice and the systematic use of episode related hints account for the enhanced problem solving skills of students.

Selcuk and Caliskan (2008) investigated the effects of problem solving instruction on physics achievement, problem solving performance and strategy use in an introductory physics course at university level. A quasi-experimental design, viz., nonequivalent pre-test post-test control group design was used. Sample for experiment consisted of two groups of student teachers (n=74). During the eight –week study one group received strategy instruction, while the other group acted as control. Data of the study was collected by Physics Achievement Test, Problem Solving Performance Test and Problem Solving Performance scale. Findings of the study indicated that strategy instruction was effective on physics achievement, problem solving performance, and strategy use.

Gaigher, Rogan, and Braun (2007) conducted a study on the effect of a structured problem solving strategy on problem solving skills and conceptual understanding of physics. The participants were 189 students in 16 disadvantaged South African schools. Investigators introduced new instruments, namely a solutions map and a conceptual index, to assess conceptual understanding demonstrated in students written solutions to examination problems. The process of development of conceptual understanding was then explored within the frame work of Greeno's model of scientific problem solving and reasoning. It was found that the students who had been exposed to the structured problem solving strategy demonstrated better conceptual understanding of physics and tented to adopt a conceptual approach to problem solving.

Krusberg (2007) evaluated three emerging technologies from the inter-disciplinary perspective of cognitive science and physics education research. The technologies viz., Physlet Physics, the Andes Intelligent Tutoring Systems (ITS), and Microcomputer Based Laboratory (MBL) Tools- are assessed in terms of their potential at promoting conceptual change, developing expert like problem solving skills, and achieving the goals of the traditional physics laboratory. The three technologies address different aspects of physics knowledge: Physlets, a collection of Java applets, are devised to deepen students' conceptual knowledge of physics (Cox & Dancy, 2004); the Andes Intelligent Tutoring Systems (ITS) aims to develop students' procedural knowledge of physics problem solving (Vanlehn, Lynch, Schulze, Shapiro, Taylor, & Wintersgill, 2005); and Microcomputer Based Laboratory (MBL) Tools, a set of laboratory probes and associated software, seek to relieve the physics laboratory of the drudgery of data collection and display (Sokoloff, Laws, & Thornton, 2007). Krusberg concluded that the emergence of these technologies have a profound impact on all areas of physics instruction, from course management to problem solving instruction and to data collection in the laboratory.

Ding and Harskamp (2006) explored the influence of partner gender on female students' learning achievement, interaction and the problem solving process during cooperative learning. 50 students (26 females and 24 males), drawn from two classes of a high school, took part in the study. Students were randomly paired, and there were three research groups: mixed gender dyads (MG), female-female dyads (FF) and male-male dyads (MM). Analysis of students' pre- and post-test performances revealed that female students in the single gender conditions solved physics problems more effectively than those in the mixed-gender condition, while the same was not the case for male students. They further explored the differences between female and male communication styles, and content among the three research groups. It showed that the female interaction content and problem solving processes were more sensitive to partner gender than were those for males.

Friege and Lind (2006) studied the importance of ‘types’ and ‘qualities’ of knowledge in relation to problem solving in physics. The sample of the study include students (N=138) of an intensive beginner college course in physics. They found that conceptual declarative knowledge and problem scheme knowledge are excellent predictors of problem solving performance. They also claim that declarative knowledge is more typical for low achievers or novices in physics problem solving whereas problem scheme knowledge is predominantly used by high achievers or experts. They distinguished two dimensions of knowledge ‘types’ and ‘qualities’. Knowledge types are problem solving relevance and single knowledge elements. Knowledge qualities are structure of discipline and organized knowledge units.

Jonassen and Strobel (2006) identified six different features of a good mental model. They are (i) structural knowledge involving concepts in a domain, (ii) procedural knowledge involving a plan for solving the problem, (iii) image or images of the system being explored, (iv) associations or metaphors, (v) executive knowledge or the knowledge of when to activate mental models, and (vi) beliefs or assumptions about the problem. They also suggested different facets of mental model development. They are (i) building a procedural model, (ii) building a structural model, (iii) building an executive model, and (iv) building arguments.

Pekrun (2006) observed that solving a complex problem is a messy, non-linear, and non-routine endeavor that requires trial and error, but setbacks during an activity can increase frustration and cause learners to lose focus from the problem.

Roll, Aleven, McLare, Ryu, Baker, and Koedinger (2006) in a study on the teaching students how to effectively use the feedback hints available from a step based tutoring system found that while help seeking tutor was guiding students help seeking behavior they compiled and learned more domain knowledge, but as soon as the help seeking tutor was turned off, they retrieved to their old gaming behavior, and their learning returned to their earlier levels.

Jonassen (2005) identified various processes learners apply towards the development of mental models. He enlisted three processes as planning, data collecting, collaborating, accessing information, data visualization, modeling and reporting.

Lorenzo (2005) reported on the development, implementation and evaluation of a problem solving heuristic. The heuristic was intended to help students understand the steps involved in problem solving and to provide them with an organized approach to tackling problems in a systematic way. The approach guided students by means of logical reasoning to make a qualitative representation of the solution of a problem before understanding calculations. The findings suggested that students found the heuristic useful in setting up and solving quantitative chemical problems, and helped them to understand the phases of the problems solving process.

Stamovlasis and Tsaparlis (2005), Tsaparlis and Angelopoulos (2000), Tsaparlis, Kousathana, and Niaz (1998), Johnstone, Hogg, and ziane (1993), Niaz and Logie (1993), and Johnstone and Kellet (1980) observed that predictive- explanatory models that are based on cognitive variables can provide a rigorous and quantitative basis for the study of the factors that affect the general problem solving ability of students, as well as the structure of the problems themselves.

Stamovlasis and Tsaparlis (2005), Stamovlasis, Kousathana, Angelopoulos, Tsaparlis and Niaz (2002), Niaz, Saud De Nunez and Ruiz De Pineda (2000), Niaz and Saud De Nunez (1991), and Niaz (1989b) observed that problem solving in chemistry requires flexibility of functioning and potential for adapting to a wide spectrum of experiences, and it is facilitated by mobility. Hence, mobility-fixity dimension is an important predictor variable of high school students' problem solving performance in chemistry.

Hong and Chang (2004) investigated the cognitive characteristics of students' decision making processes centered on phases, difficulties and strategies in personal daily life context involving biological knowledge. The study was conducted among first year science and general high school students in Seoul, Korea; 6 female students and 7 male students. The students' decision making processes were analyzed by students' 'think-aloud' and participant observation methods. It was found that the students' decision making processes progressed in the following order: recognizing a problem, searching for alternatives, evaluating the alternatives, and decision. During the decision making processes, these phases were repeated by trial and error. It was observed that students had a tendency to have difficulties in analyzing the difference between initial state and desirable state of the problem, organizing knowledge related problems, and clarifying values as selective criteria.

Park and Lee (2004) studied the factors to be considered while solving everyday context physics problems. 93 high school students, 36 physics teachers, and nine university physics educators participated in their study. They used two types of physics problems viz., everyday contextual problems (E-problems) and de-contextualized problems (D-problems). It was found that even though there was no difference in the actual performance between E-problems and D-problems, subjects predicted that E-problems where more difficult to solve. Subjects preffered E-problems from a school physics text because they thought E-problems were better problems. Based on the observations of students' problem solving processes and interviews with them, six factors were identified that could impede successful solution of E-problems. They include ability to grasp a problem situation, ability to extract relevant information from long sentences, ability to ignore irrelevant information, ability to use complex variables, and the ability to draw conclusion without subjective judgments. They also found that many physics teachers agreed that students should be able to cope with these factors. However teachers' perceptions regarding the need for teaching these factors were low. Therefore they suggested teacher reform through in-service training courses to enhance skills for teaching problem solving in an everyday context.

Stamovlasis and Tsaparlis (2003) and Johnstone and Selepeg (2000) observed that science material to be learned seemed more familiar to high processors and they had higher achievement even in mental task that do not require high processing capacity, such as memorizing algorithms or recalling of learned schemata.

Tsaparlis and Zoller (2003), and Zoller and Tsaparlis (1997) found that the design of teaching strategies that can facilitate conceptual understanding, plus the use of a variety of problems of variable logical structure and of demand for information processing and in particular for extended use of novel problems can provide for a means for the development of various cognitive abilities, and for effecting the transition from lower to higher order cognitive skills.

Lee, Tang, Goh, and Chia (2001) opined that in order to improve pupil’s ability to solve problems in science, special attention should be paid to two main issues: to develop in students problem solving skills through science education, and to look at the difficulties faced by students in this area and find ways to help them overcome these difficulties.

Taconis, Fergusson-Hessler and Broekkamp (2001) analyzed a number of articles published between 1985 and 1995 in high standard international journals, describing experimental research on the effectiveness of a wide variety of teaching strategies for science problem solving. They found that both providing learners with guidelines and criteria they can use in judging their own problem solving process and products, and providing immediate feedback to them were found to be important prerequisites for the acquisition of problem solving skills.

Tao (2001) explored high school students’ collaborative efforts in solving qualitative physics problems. The study investigated whether and how confronting students with varying views help to improve their problem solving skills and develop better understanding of the underlying physics concepts. The varying views were provided to twelve, 18 year old students by requiring them to work in dyads of three problems during which they have to consider and confront with each others’ ideas; and to consider, in a feedback session, multiple solutions to each problem, comparing the solutions with their own and reflecting on their mistakes. The study adopted Marton’s emerging theory of awareness as its theoretical underpinning (Marton & Booth, 1997). The results of the study showed that confronting students with varying views have positive effects on students’ learning, thus supporting Marton’s theory of awareness.

Bransford, Brown, and Cocking (2000) observed that novices may have stored knowledge of procedures, rules, and formulas but they do not have sufficiently integrated sets of mental models. Therefore they fail to recognize what conditions warrant the application of knowledge and why is it relevant. They also observed that, expert knowledge is more integrated into coherent mental model. They includes specifications of when where and why to use their knowledge. This will increase their speed and accuracy during problem solving.

Tsaparlis and Angelopoulos (2000) noted that in order for the working memory model to be valid, a number of necessary conditions must be fulfilled, namely, (i) the logical structure of the problem must be simple; (ii) the problem has to be non algorithmic; (iii) the partial steps must be available in the long term memory and accessible from it; (iv) the students do not employ chunking devices; (v) no 'noise' should be present in the problem statement.

Mayer's (1998) effort based learning principle states that students think harder and process materials more deeply when they are interested and believe that they are able to solve the problem. Such students are said to have high self-efficacy.

Zhang (1997) found that externalizing representations of problems have numerous benefits for helping novices to manage problem complexity such as limiting abstraction, aiding interpretation of information, recognizing invariant information, seeing a situation from different perspectives, and making inferences. They also help to extend working memory, store information, and share knowledge.

Leonard, Dufresne, and Mestre (1996) pointed out that although solutions to physics problems lay out in textbook or by instructors in class usually briefly state that the principles or concepts being applied, they do not always specifically justify why these principles or concepts are the appropriate ones. Only solutions and equations which encapsulate the principles are written down. Students there for perceive that it is the finding and manipulation of equations that lead to answers and they regard the principles as abstractions, which are somehow separate from the real business of problem solving. In reality understanding and doing physics consists of being able to select the central ideas appropriately and then apply them across a wide range of problems. Therefore, the researchers believe that the only way to convince students of this reality is to separate out 'strategy' from solution. They define strategy as statement of major principles or concepts that apply in the problem situation, a justification of why they apply, and a qualitative description of the steps by which they can be used to arrive at a solution, with the focus firmly on the cognitive rather than the procedural skills.

Renni and Parker (1996) showed that everyday contexts that are familiar to students help in their problem solving. Researchers used two sets (real life problems and abstract ones) of matched physics problems, and observed that seven out of eight students performed better with real life problems when compared with abstract ones. In the interview students said that everyday context problems were easier to visualize or figure out what was happening and could create interest.

Dunkle, Schraw and Bendixen (1995) observed that performance in solving well defined problems is independent of performance on ill-defined tasks, with ill-defined problems engaging a different set of epistemic beliefs.

According to Zhang and Norman (1994) high-level cognitive functions result from the learner's internalization of information in the environment and the externalization of internal representations. They theorized internal and external representations as equal partners during problem solving, with external representations activating perceptual processes and internal representations activating cognitive processes.

Mayer (1992) opined that novices do not possess well developed problem schemas and are not able to recognize problem types. So they rely on general information processing approaches to problem solving. This provides weak strategies for problem solutions.

Song and Black (1992) observed that students showed better performances with everyday context problems when scientific concepts applications were not required to solve problems. However students showed no difference between everyday or scientific contexts in problems requiring specific concept application.

Song and Black (1991), while using the Assessment Performance Unit categorization of the scientific process skills, observed that students showed higher levels of achievement in problems requiring interpretational skills in an everyday context, whereas in problems requiring application skills their performances where better in a scientific contest.

Robertson (1990) conducted a study on detection of cognitive structure with protocol data. He found that the extent to which think- aloud protocols contained relevant structural knowledge was a strong predictor of how well learners would solve transfer problems in physics than either attitude or previous experience in solving similar problems. He concluded that structural knowledge that connects formulas and important concepts in the knowledge base are important to understanding physics principles.

Johnstone and El-Banna (1986, 1989) put forward the working memory model. It states that a student is likely to be successful in solving a problem if the problem has a mental demand (M-demand or Z-demand) which is less than or equal to the subject's working memory capacity. But the student fail or will be unsuccessful in solving the problem if the mental demand of the problem is more than the working memory, unless the student has strategies that enable him/her to reduce the value of mental demand.

Saunders and Jesunathadas (1988) investigated whether the familiarity of task content effect problem solving requiring prepositional reasoning. They observed that there was a similar interaction effect between the familiarities of contents with the levels of difficulty in prepositional reasoning required for a problem.

Sweller (1988) opined that experts are good problem solvers because they recognize different problem states that invoke certain solutions. If the type of problem is recognized, then little searching through the problem space is required.

Perkins, Hancock, Hobbs, Martin, and Simmons (1986) found that some students, when faced with a computer programming problem, would disengage immediately, believing that it was too difficult, while others would keep trying to find a solution. They opined, if problem solvers do not believe in their ability to solve problems, they will most likely not exert sufficient cognitive effort and therefore not succeed. Their self confidence of ability will predict the level of effort and perseverance that they will apply to solve the problem.

Simon (1978) opined that in general, the processes used to solve ill-structured problems are the same as those used to solve well structured problems.

Indian studies on problem solving in academic context

Sumangala and Rinsa (2012) conducted a survey on the interaction effect of thinking styles and deductive reasoning on problem solving ability in mathematics of secondary school students. A sample of 500 high school students of Malappuram and Kozhikode districts in Kerala participated in the study. Test of Problem Solving Ability in Mathematics, Test of Deductive Reasoning and Thinking Style Inventory were used as tools for the study. The investigators found that deductive reasoning and executive thinking styles are crucial for a good problem solver. They suggested that teachers should find out and develop instructional strategies to bring up the child to use Executive Thinking Style, and give chance for developing reasoning ability so as to enhance problem solving ability in mathematics.

Manoj Praveen (2006) conducted a study on the effect of mastery learning strategy on problem solving ability in physics of secondary school students. The study employed a pre-test post-test control group design with 40 students in each group of grade 9 students. The groups were matched on nonverbal intelligence, verbal intelligence and socio-economic status. The investigator found that mastery learning strategy does not significantly foster the mental processes and skills associated with problem solving of students better than conventional strategy. The investigator suggested that the ability to solve problems develop only by handling diverse problems and that the students should workout different problems on the same concept using different intellectual ways.

Sumathy (1994) studied the hemisphericity, divergent thinking and problem solving ability in physical science of the plus two students in Selam and found that boys and girls did not show any difference in the deductive thinking skill, inductive thinking skill, analytical thinking skill, convergent thinking skill, divergent thinking skill and symbolic thinking skill. She also found that girls were better than boys in solving problems involving recall/ recognition and in problems involving more than one principle skill and synthetic skill.

Kumari (1991) studied the problem solving strategies and some cognitive capabilities of 10-12 year old children. The study revealed that the problem solving ability and success on different types of problems are significantly and positively related to each cognitive capability separately as well as globally. She also found that there are some sequential steps in problem solving at different forms or levels of responses to be associated with the tactics used by children.

Gill (1990) studied the effect of training strategies on creative problem solving abilities and cerebral dominance in relation to intelligence, personality and cognitive style. The study showed that right-brain training strategy was superior to the left-brain training strategy, as far as creative problem solving abilities in mathematics were concerned. The group having the field independent cognitive style scored higher on originality than the field dependent group on creative problem solving ability test.

Dutt (1989) investigated the effect of problem solving strategies on problem solving ability in science and examined its relationship with certain cognitive and personality variables. The used tools of problem solving ability test in science developed by the investigator; the group embedded figure test

(GEFT); the General Mental Ability Test; and the Comprehensive Anxiety Test. The investigator found that strategies of problem solving significantly affect problem solving ability. He also found that focusing strategy is superior to scanning strategy and that the high intelligent students, irrespective of the strategies of training scored high on Problem Solving ability test than low intelligent students.

Banerji (1987) investigated the effect of instruction in programming in logo upon problem solving achievement of selected high school students. He used the graphic mode of the programming language, LOGO as a method of teaching mathematics and problem solving. The results suggested that the new method had significant positive effect on students' application of problem solving strategies and ability to understand problem statements. Qualitative observations further suggested improvements in some of the components of problem solving abilities, but not in all.

Jain (1982) conducted a study on the problem solving behavior in physics of adolescent pupils. He found that students who initially failed to solve physics problems correctly were able to solve most of the problems completely correct or partially correct after providing hints related to problem solving strategies. He also found that the problem solving scores differed significantly among the three groups of students based on their IQ levels and also among students based on their level of intellectual development.

Conclusion on research related to problem solving

The research related to problem solving focused on three major aspects namely, comparison of problem solving behavior differences among expert and novice problem solvers, what contribute to the development of problem solving skills, and teaching problem solving strategies in order to make the novices become expert problem solvers.

The earliest one of these is the comparison of problem solving behavior differences among expert and novice problem solvers (Chi, Feltovich, & Glaser, 1981; de Jong & Ferguson-Hessler, 1986; Dhillon, 1998; Larkin, McDermott, Simon, & Simon, 1980; Reif, & Heller, 1982; Veldhuis, 1990; riest, & Lindsay, 1992; Zajchowski & Martin, 1993). Investigations on the strategy use of the expert and novice problem solvers reveal that, experts have a tendency of first analyzing the problem qualitatively by depending of the fundamental physics concepts before starting to solve the problems using equations. Whereas novices usually starts to solve the problems using mathematical equations, substituting the given variables, and then investigating other equations where they can substitute the other quantitative variables. Expert problem solvers usually proceed through four phases of analysis when they are faced with a challenging quantitative problem. These phases include, conceptual analysis or exploring the problem, strategic analysis or planning for a solution procedure, quantitative analysis or implementing the plan, and meta-analysis or reflecting and checking the solution. In typical problem solving instruction, only quantitative analysis is explicitly modeled for the students, leaving them to develop other skills on their own (Gerace & Beatty, 2005). Novices use their conceptual, declarative knowledge in the first place for solving problems. Therefore these variables act as the predictor of their problem solving skills. Experts have problem schemes at their disposal in addition to declarative knowledge. Therefore both problem scheme and declarative knowledge act as the predictor of their problem solving skills (Friege & Lind, 2006).

Later studies that concentrated on what factors contributed to problem solving skills (Robertson, 1990) suggest that the type of knowledge viz., conceptual declarative knowledge, structural knowledge and problem scheme knowledge contribute significantly to problem solving skills (Friege & Lind, 2006). Researchers also emphasis the role of organizing knowledge and finding the relationship between concepts to make them better utilized during problem solving (Beyer, 1984; de Jong & Ferguson-Hessler, 1986; DeBono, 1983; Ferguson-Hessler &de Jong, 1990; Gorden & Gill, 1989; Jonassen, 2000; Lee, 1985; Lee, Goh, China, & Chin, 1996; Longo, Anderson &Wicht, 2002; O'Neil &Schacter, 1999; Palumbo, 1990; Schkade & Kleinmuntz, 1994). Research identifies use of concept maps as an apt method to organize knowledge and express the relationship between concepts. It is an accepted method of teaching and learning (Abel & Freeze, 2006; Daley, Shaw, Balistrieri, Glasenapp, & Piacentine, 1999; Ertmer & Nour, 2007; Hinck, Webb, Sims-Gidden, Helton, Hope, Utley, Savinske, Fahey, & Yarbyough, 2006). In addition to type of knowledge, other factors like working memory, familiarity, and epistemic beliefs etc. also seem to influence problem solving. The most important of these is metacognition. Many researchers conclude that the use of metacognitive strategies like planning, executing (implementing), and Checking (evaluating) establish problem solving abilities (Artz & Armour-Thomas, 1992; Brown, Bransford, Ferrara, & Campione, 1983; Horak, 1990; Kramarski & Mevarech, 2003; Muis, 2007; Muis, Gina, & Franco, 2010; Otero, Campanario, & Hopkins, 1992).

Recent researches on problem solving in physics are directed towards teaching problem solving strategies in order to make the novices become expert problem solvers (Foster, 2000; Heller, Keith, & Anderson, 1992; Huffman, 1997; Larkin & Reif, 1979; Mestre, Dufresne, Gerace, Hardiman, &

Touger, 1993; Selcuk & Caliskan, 2008; van Weeren, 1982). Explicit problem solving instruction directly teaches students how to use more advanced techniques for solving problems. Review of literature reveals that four important factors need special consideration while instructing strategies to develop problem solving skills viz., well organized concept knowledge, proper representation of problem, practice of metacognitive strategies, and peer interaction. In addition to these factors current studies investigate the use of cognitive tools in computer settings during problem solving.

Earlier studies on developing problem solving skills in science were conducted mainly among young children. Later studies on problem solving were extended to high school children (Ding & Harskamp, 2006; Gaigher, Rogan, & Braun, 2007; Pathak, Kim, Jacobson, &Zhang, 2011; Pol, Harskamp, Suhre, & Geodhart, 2008). Current studies on developing problem solving abilities in physics are done in engineering (Bacerra-Labra, Gras-Marti, & Torregrosa, 2012; Hong, Chen, Wong, Hsu, &Peng, 2012) and university undergraduates (Berge & Danielsson, 2012; Mellingsaeter & Bungum, 2014; Stadler & Garcia, 2013; Stadler & Garcia, 2013; Uhden, Karam, Pietrocola, & Pospiech, 2012).

Review of studies related to problem solving particularly in India reveal that most of such studies concentrated on finding relation between problem solving ability and various cognitive and psychological variables (Dutt, 1989; Gill, 1990; Kumari, 1991; Sumangala & Rinsa, 2012; Sumathy, 1994). Some studies have explored the possibilities of enhancing problem solving skills using existing techniques of teaching without complete success (Banerji, 1987; Jain, 1982; Manoj Praveen, 2006). In this scenario the investigator feels the necessity to develop an instructional strategy that focuses on the enhancement of problem solving skills and explore its effectiveness.

Studies on Metacognitive Strategies in Problem Solving

Educational research on metacognition and its possibilities in teaching learning process are more recent compared to that of problem solving. Studies exploring the nature of development of metacognition, various metacognitive strategies and their effect on students' achievement with special reference to problem solving is dealt in this section. A number of studies conducted in the period 1983-2014 are reported in decanting chronological order. A sub-section of Indian studies on metacognition is also included.

Hargrove and Nietfeld (2014) examined the impact of teaching creativity in the form of associative thinking strategies within a metacognitive framework. A representative sample of 30 university design students were selected from a larger section (N=122) to participate in a 16 week supplemental course. Each week a new creative thinking strategy was integrated with activities to encourage metacognitive skill development. Upon completion of the course, the treatment group had significantly higher scores on fluency and originality measures compared with their matched peers. In addition, students in the treatment condition received higher ratings on a summative domain-specific process judged by external design experts. Metacognitive Awareness Inventory scores increased for the treatment group but were stable over time for the comparison group.

Wang, Chen, Fang, and Chou (2014) explored the science reading metacognition and comprehension of Taiwanese students using a Chinese–language version of the Index of Science Reading Awareness. Structural equation modeling results confirmed that the underlying model comprised three clusters of metacognitive knowledge, viz., belifs and confidence in science reading, knowledge of structure of science text, and knowledge of science reading strategies. The research provided evidence on the relationship between metacognitive awareness and comprehension of science text. The study also revealed that metacognitive awareness of science reading deteriorated from elementary to middle school, both in Canadian and Taiwanese students.

Hargrove (2013) assessed the long term impact of a metacognitive approach to creative skill development of students. The study tracked design students beginning their freshman year to determine if observed improvement have been maintained throughout 4 years of undergraduate study. Preliminary research statistically tested the introduction of structured metacognitive skills on the development of creative thinking ability for a diverse population of undergraduate design students. The research indicated that an approach to education influenced by research in learning theory and metacognition does, in the short term; result in students who are more creative. Further, continuing testing throughout students' education showed that students who participated in one or more interventions finished with significantly higher levels of creative thinking. The study also demonstrated how newly structured educational interventions utilizing online blogs and other internet based technologies were successful in enhancing and maintaining students creative thinking abilities. It provides educators with a plan of action consisting of a toolbox of creative strategies and a framework for a reflective approach.

Taasoobshirazi and Farley (2013) developed a 24-item Physics Metacognition Inventory to measure physics students' metacognition for problem solving. The items in the inventory were classified in to eight sub-concepts subsumed under two broad components: knowledge of cognition and regulation of cognition. The researchers found that students' score on the inventory were reliable and were related to students' physics motivation and physics grades. An exploratory factor analysis provided evidence of construct validity revealing six components of students' metacognition while solving physics problems, including: knowledge of cognition, planning, monitoring, evaluation, debugging, and information management. Although women and men differed on the components, they had equivalent overall metacognition for problem solving.

Thomas (2013) argues that problems persist with physics learning in relation to students' understanding and use representations for making sense of physics concepts. He further argued that students' views of physics learning reflect a surface approach to learning that focuses on mathematical aspects of physics often passed on via textbooks and lecture-style teaching. In this context he reported on a teacher's effort to stimulate students' metacognitive reflection regarding their views of physics learning and their physics learning processes via a pedagogical change that incorporated the use of a representational framework and metaphors. As a consequence of teacher's pedagogical change, students metacognitively reflected on their views of physics and their learning processes and some reported changes in their views of what it meant to understand physics and how they might learn and understand physics concepts.

Bryce and Whitebread (2012) conducted a study that aimed to better understand how metacognitive skills develop in young children aged 5 to 7 years. The researcher developed a new observational method to better represent young children's (n=66) metacognitive skills by coding their verbalizations and non-verbal behavior during a problem solving task. The method proves to be developmentally sensitive and illustrated both a quantitative increase in metacognitive skills, and qualitative changes in the types of monitoring and planning used throughout early development. The results of the study further indicated that monitoring processes further improve with age, control processes improve with both age and task specific ability, and failures of metacognitive skills are primarily effected by task specific ability rather than age.

Jacobse and Harskamp (2012) investigated how to effectively measure metacognition in problem solving. They conducted an empirical study in grade five (n=39), using a new instrument for the assessment of metacognition in word problem solving. The new instrument combined the students' performance judgments and problem visualizations. It was administrated to groups of students and its predictive validity in problem solving was compared to well-known think-aloud measure and self-report questionnaire. Think-aloud protocols are valid, but time consuming method to assess metacognition with practical drawbacks. Self-report questionnaires are less valid, but easy to use. Analysis showed that the new instrument did overlap with the think-aloud measure and both predict problem solving.

Lubin and Ge (2012) discussed a qualitative study that examined students' problem solving, metacognition and motivation in a learning environment designed for teaching educational technology to pre-service teachers. The researchers converted a linear and didactic learning environment in to a new learning environment by contextualizing domain related concepts and skills and providing ill-structured, collaborative problem solving opportunities. The intervention called Learning Environment

Approaching Professional Situations (LEAPS) took in to account issues surrounding motivation and situativity that are of particular interest to instructional developers and design-based researchers. Four classes were assigned as either traditional or LEAPS environments from which four cases were selected for further examination. The results suggested that the LEAPS approach was beneficial in supporting students' problem solving, motivation, and self-reflections, but only under specific conditions.

Meijer, Veenman, and van Hout-Wolters (2012) investigated joint as well as independent influences of intelligence and metacognition of learning results. 13 year old school students participate in the study. Intelligence was measured by standardized test for reasoning, spatial ability and memory. Measures of metacognitive activity was gathered by analysis of think-aloud protocols within two task domains viz., history and physics. Prior knowledge and learning results were measured by tests constructed by the researchers. The results showed that metacognitive activity did not relate to learning results in either task domains. For history, the learning result was only determined by prior knowledge. For physics, intelligence influenced the learning results via prior knowledge but the effect of execution activity appeared more important. Researchers proposed that 'learning by doing' is a powerful means for promoting the application of knowledge in physics.

Ozosy (2011) investigated the relationship between fifth grade students' metacognitive knowledge and skills, and mathematics achievements. A total of 242 students from six different schools participated in the study. Turkish version of Metacognitive Knowledge and Skills Assessment (MSA-TR) was used to measure metacognitive knowledge and skills. The results demonstrated a significant and positive relationship between metacognition and mathematics achievement. Results further showed that 42% of total variance of mathematics achievement could be explained by metacognitive knowledge and skills.

Demircioglu, Argun, and Bulut (2010) investigated pre-service secondary mathematics teachers' metacognitive behavior in the mathematical problem-solving process. The case study methodology was employed with six pre-service mathematics teachers enrolled in one university at Ankara, Turkey. Data was collected using think aloud method for two sessions. The study found no relationship between academic achievement and frequencies of metacognitive behavior; however the types of problems effected the frequencies. The study also revealed that there was no pattern in metacognitive behavior with respect to achievement and type of problem.

Magno (2010) investigated the influence of metacognition on critical thinking skills. The Metacognitive Assessment Inventory (MAI) which measures regulation of cognition and knowledge of cognition and the Watson-Glaser Critical Thinking Appraisal (WGCTA) with the factors inference, recognition of assumptions, deduction, interpretations, and evaluation of arguments were administered to 240 college students from different universities in the National Capital Region in the Philippines. The Structural Equations Modeling (SEM) was used to determine the effect of metacognition on critical thinking as latent variables. The results indicated that metacognition offered a significant path to critical thinking and that for both metacognition and critical thinking, all underlying factors are significant.

Muis, Gina, and Franco (2010) demonstrated that for self-reported metacognitive strategies, students profiled as both rational and empirical had the highest frequency of metacognitive strategy use compared to students profiled as empirical. Similarly during problem solving, students profiled as both rational and empirical had the highest frequency of regulation of cognition compared to students profiled as empirical or rational. Finally students profiled as both rational and empirical attained higher levels of problem solving achievement compared to students profiled as empirical.

Peters and Kitsantas (2010) examined the effectiveness of a metacognitive prompts intervention-science (MPI-S), which is based on the nature of science with 162 eighth grade science students. Findings showed significant improvement in students' content knowledge and knowledge about the nature of science in the experimental group. In addition, qualitative finding revealed that the experimental group made choices based on evidence in the inquiry unit whereas the comparison group made decisions based on authority.

Schneider and Artelt (2010) analyzed the role of metacognition in education in general and mathematics education in particular based on theoretical and empirical work from the last four decades. The study emphasized the importance of metacognition in mathematical education. It concluded that though the impact of declarative metacognition in mathematics performance is substantial, the normal learners as well as those with especially low mathematics performance do benefit substantially from metacognitive instructional procedures.

Wilson and Bai (2010) investigated teachers' understanding of metacognition and their pedagogical understanding of metacognition, and the nature of what it means to teach students to be metacognitive. 105 graduate students in education participated in the study. The study used mixed research method for data analysis. Researchers suggested that the participants' metacognitive knowledge had a significant impact on their pedagogical understanding of metacognition. They also found that teachers who have a rich understanding of metacognition reported that teaching students to be metacognitive require a complex understanding of both the concept of metacognition and metacognitive thinking strategies.

Yilmaz-Tuzun and Topcu (2010) investigated elementary students' epistemological beliefs, metacognition and their relationship to students perceived characteristics of constructivist learning environment. A total of 626 students in 6th, 7th and 8th grades of nine elementary public schools in Turkey constituted the participants of the study. Constructivist learning environment survey (CLES), Junior Metacognitive Awareness Inventory (Jr.MAI), and Schommer epistemological belief questionnaire (EB) were administered to students. Factor analysis of Jr. MAI revealed that both knowledge of cognition and regulation of cognition items were loaded in to one factor. Confirmatory factor analysis of EB revealed a four factor structure namely, innate ability, quick learning, omniscient authority, and certain knowledge. Regression analysis revealed that metacognition and omniscient authority were significant predictors of personal relevance dimension of CLES. Metacognition was found as the only predictor of the student negotiation. Innate ability and metacognition contributed to the model more than epistemological beliefs for all three dimensions of CLES.

Downing, Kwong, Chan, Lam, and Downing (2009) compare an entirely problem-based approach to learning and teaching with traditional methods. The study was conducted among first year undergraduates at a Hong Kong University (N=66). Learning and Study Strategies Inventory (LASSI) was used to measure student perceptions of their thinking, or metacognition.

The researchers also explored difference in metacognitive development between each group of students at the beginning and at the end of their first year in each programme. Researchers argue that, in addition to the formal learning context everyday challenges emerging from the additional new social context provided by the problem based curricula provides fertile environments for the development of metacognition.

Jacobse and Harskamp (2009) developed a computer program to improve students' metacognitive and problem solving skills. The program consisted of word problems and metacognitive hints. The experimental group of grade 5 (n=23) practiced with the computer program, in which the students were free to choose metacognitive hints during problem solving. The control group (n=26) did not work with the computer program. Results showed that students who used the metacognitive program outscored the students in the control group on the problem solving post-test and improved their problem solving skills. The findings showed that metacognitive skills can be enhanced by students' free choice of metacognitive hints in a computerized learning environment and that the use of hints can increase students' performance in solving word problems.

Whitebread, Coltman, Pasternak, Sangster, Grau, Bingham, and Demetrion (2009) reported on observational approaches developed within a UK study to the identification and assessment of metacognition and self-regulation in young children in the 3-5 year age range. The analyses of 582 metacognitive or self regulatory video-taped events were described, including the development of a coding frame work identifying verbal and nonverbal indicators. The construction of an observational instrument, the Children's Independent Learning Development (CHILD, 3-5) checklist was also supported together with evidence of the reliability with which it can be used by classroom teachers. The authors argue that the establishment of metacognitive and self regulatory capabilities of young children by means of the kinds of observational tools developed within the study also had clear and significant implications for models and theories of metacognition and self regulation.

Yuruk, Beeth, and Andersen (2009) investigated the effect of meta-conceptual teaching interventions on students' understanding of force and motion. A multi-method research design including quasi-experimental designs and case study designs was employed to compare the effect of meta-conceptual activities and traditional instruction and investigate students' reactions to meta-conceptual teaching interventions. 45 high school students in USA were enrolled in one of the two physics classes instructed by the same teacher. In the experimental group students' engagement in meta-conceptual knowledge and processes were facilitated through various instructional activities including, postal drawing, journal writing, group debate, concept mapping and class and group discussions. In the comparison group, the same content knowledge was explained by the teacher along with the use of laboratory experiments, demonstrations and quantitative problem solving. The results showed that students in the experimental group had significantly better conceptual understanding than their counterparts in the comparison group and the positive impact remained after a period of nine weeks.

Kung and Linder (2007) explored natural-in-action metacognitive activity during the student laboratory in university physics, with an aim towards quantifying the amount of metacognition used by the students. The study investigated whether quantifying natural-in-action metacognition is possible and valuable for examining teaching and learning in laboratory. Video recordings of student groups working during three types of physics laboratories were transcribed and then coded using a coding scheme developed from related research on mathematical problem solving. The scheme identified groups' general behavior and metacognitive activity. The researchers recognized that reliably identifying metacognition is challenging. Results of the study suggested that a greater amount of metacognition do not improve students' success in the laboratory, what matters in whether the metacognition causes the students to change behavior. The study indicated that it is important to consider the outcome of metacognition not just the amount.

Muis (2007) Proposed four phases of self-regulated learning and four areas of regulation. The four phases include (i) task definition, (ii) planning and goal setting, (iii) enactment, and (iv) evaluation. The four areas of regulation proposed include (1) cognition, i.e., knowledge activation and knowledge of strategies, (2) motivation and affect, i.e., achievement goals, achievement attributions and self-efficacy, (3) behavior, i.e., time and effort, and (4) context i.e., resources and social context.

Abdullah (2006) observed that metacognitive skills are relevant in physics problem solving. He also observed that the form of a problem with words plus a diagram is a way of reducing memory overload.

Meijer, Veenman, van Hout-Woulters (2006) constructed a hierarchical taxonomy of metacognitive activities for the interpretation of thinking-aloud protocols of students in secondary education, who studied texts on history and physics. After testing an initial elaborate taxonomy on multiple raters, it appeared that the inter-rater correspondence was well below par. The categories in the taxonomy were too highly specified. Categories were combined and tested on new protocols in a cyclic fashion and they constructed a revised taxonomy consisting of 16 history protocols and 16 physics protocols for coding. Frequencies of occurrence of metacognitive activities as well as the judgment of the quality of metacognitive activities of the participants were collected. Researchers found that there is a reasonable correlation between the frequency method and the quality method for coding thinking aloud protocols.

Kramarski and Mevarech (2003) reported the results of an investigation on the effects of metacognitive training on the mathematical reasoning and metacognitive skills of eight- grade students. They reported that students received metacognitive instruction in either cooperative or individualized learning situation out-performed comparison students in their ability to interpret graphs, fluency and flexibility of mathematical explanations, use of logical arguments to support math reasoning, performance on transfer tasks, and level of domain specific metacognitive knowledge. They recommended facilitating students with sets of metacognitive questions, containing comprehension questions, strategic questions and connection questions to be completed during the task. Comprehension questions were designed to encourage the students to reflect on a problem before solving it. Strategic questions were designed to encourage students to think about what strategies might be appropriate for a given task and to provide a reason for choosing that strategy. Connection questions were designed to encourage students to recognize deep structure of the problem so that they could activate relevant background knowledge and solution strategy.

Teong (2003) conducted a study to establish the extent to which metacognitive training plays a part in students' word problem solving in a computer environment. The study was conducted in 11-12 year old students (N=142) from two primary schools in Singapore. The study consisted of two phases, a quasi-experimental phase and a case study phase. For the quasi-experimental design, analysis of students' mathematical achievement test data is used to investigate the relationship between metacognitive training, students' level of mathematical achievement and their mathematical word problem solving performance. For the case study design, analysis of the think-aloud protocol data during word problem solving of eight pairs of students is used to explore the role of metacognition in mathematical word problem solving in a computer environment. In addition, student questionnaire and teacher interview data provide descriptive accounts of students' metacognitive knowledge during mathematical word problem solving. The researcher found that metacognitive training improved mathematical word problem solving performance and that the lower achievers had a full benefit from the metacognitive training only after a period of time.

Case and Gunstone (2002) argued that metacognitive development can be viewed as a shift in the approach to learning used by a student. Based on this argument they investigated the metacognitive development of a group of students on a course that aimed the metacognitive development towards deep approaches in learning and conceptual understanding among university students. Considerable diversity was found in the approaches used by students, and the degrees to which those not initially using a conceptual (deep) approach were able to develop this approach. In those students, who were initially using an algorithmic approach, researchers made the transition fairly early in the course. Others changed to different degrees at later stages.

The students using information based approaches did not display any appreciable metacognitive development during the course. The study confirms that the promotion of metacognitive development, i.e., use of deep approaches is not easily achieved. The researchers concluded that while certain factors of a course design such as journal task and an unlimited time test, promoted metacognitive development, whereas some factors such as overall workload and time-pressured assessments mitigated against such development.

Mevarech (1999) compared the effects of three cooperative learning environments viz., (1) metacognitive training in both constructing connections and strategy application, (2) direct instruction regarding strategy application without training in constructing connections, and (3) neither metacognitive nor strategy training, on mathematical problem solving. 174 seventh grade Israeli students participated in the study. Those exposed to the metacognitive training significantly out-performed their counter parts who were exposed to the strategy instruction, who, in turn significantly outperformed the students who received neither kind of training (the cooperative control group). The researcher suggested that metacognitive training is essential to facilitate problem solving and strategy instruction is better than no training.

Msui and DeCorte (1999) are of the view that orienting and self-judging are the important metacognitive skills that are positively related to problem solving performance, and they can be learned.

Davidson and Sternberg (1998) opined that the development of metacognitive skills enable students to strategically encode the nature of the problem by mental representations of the problems , select appropriate plans for solving the problems, and identify and overcome obstacles to process.

Gourgey (1998) opined that metacognitive activities promote problem solving. He observed that while solving mathematical problems, good problem solvers work to clarify their goals, understands the concepts and relationships among the elements of a problem, monitor their understanding, and choose and evaluate actions that lead towards the goal.

Schraw (1998) describes metacognition as a multidimensional set of general, rather than domain-specific, skills that are distinct from general intelligence. He suggests that these skills may help to compensate for deficits in general intelligence and /or prior knowledge on a subject during problem solving. He also cites a number of empirical studies that shows that cognitive knowledge facilitate cognitive regulation. He observes that about one-quarter of the variance in cognitive knowledge is attributable to cognitive regulation and vice versa.

Lester (1994) opined that problem solving requires knowing not only what to monitor but also how to monitor one's performance and sometimes unlearning bad habits. He regarded metacognitive activities as a driving force in problem solving along with beliefs and attitudes.

Artz and Armour- Thomas (1992) suggest the importance of metacognitive processes in mathematical problem solving in a small group setting. According to them, a continuous interplay of cognitive and metacognitive behaviors is necessary for successful problem solving and maximum student involvement.

Otero, Campanario, and Hopkins (1992) developed an instrument for measuring metacognitive comprehension monitoring ability (CMA) that does not rely entirely on subjects' self reports. They found that CMA was significantly related to academic achievement as measured by marks.

Horak (1990) found that there are interactions between students' cognitive style (field dependence/ independence) and their use of problem solving heuristics and metacognitive processes.

Cross and Paris (1988) describe an intervention targeted at improving the metacognitive skills and reading comprehension of 171 students in third and fifth grades. During instruction students received strategy training that included explicit attention to declarative, procedural and conditional knowledge about reading strategies. Students in both grades showed significant gains in evaluation of task difficulty and one's own abilities, planning to reach a goal, and monitoring progress towards the goal.

Haller, Child, and Walberg (1988) identified three clusters of mental activity inherent in metacognition. They are awareness, monitoring and regulating. Awareness refers to recognition of explicit and implicit information and responsiveness to inaccuracies. Monitoring entails goal setting, self-questioning, paraphrasing, activating relevant knowledge, making connections between new and previously learned content, and summarizing. Regulating involves compensatory strategies to redirect and bolster flattering comprehension.

Haller, Child, and Walberg (1988) meta-analyzed 20 empirical studies. These studies were on the effects of metacognitive instruction on students' metacognition during reading. They found that the most effective instructional strategies include the textual dissonance approach, self-questioning and the backward- forward strategies.

Brown, Bransford, Ferrara, and Campione (1983) proposed metacognition can be divided into two components: knowledge of cognition and regulation of cognition. Knowledge of cognition refers to the relatively stable information that learners have about their own processes including knowledge of how they store or retrieve information. Regulation of cognition refers to processes of planning activities prior to engaging in a task, monitoring activities during learning, and checking outcomes against set goals. These processes are assumed to be unstable and dependent on task and situation.

Kitchener (1983) developed a three level model of cognitive processing that distinguishes between cognition, metacognition and epistemic cognition whereby each level builds from the previous level. At the cognitive level, processes such as sensing, decoding, and reasoning occur. At metacognitive level, metacognitive processes include planning strategies, monitoring progress and control. In the last level called epistemic cognition, functions is in synchrony with the other two levels and includes the monitoring of the epistemic nature of learning and problem solving.

Indian studies on metacognition in educational contexts

Priya (2013) developed a learning package in biology integrating the process and skills of metacognition at the secondary school level and investigated the effect of this package in enhancing metacognitive skills and achievement in biology of secondary school students. The investigator also examined the effect of the package on science interest and attitude towards science. In the study, the investigator adopted the pre-test post-test non equivalent group design. The study revealed that the learning package based on the metacognitive process enhance metacognitive skills and achievement in biology of secondary school students. The investigator further found that the learning package based on metacognitive process is more effective than activity oriented method of instruction in enhancing science interest and attitude of secondary school students towards science.

Gafoor and Shareeja (2012) developed a metacognitive strategy instruction for enhancing problem solving skills in physics that incorporates the ideas of organizing knowledge through concept maps, diagrammatic representation of problem, and use of metacognitive strategies/ skills. A pilot study was conducted to find the effect of this newly developed Metacognitive Strategy Instruction on solving problems in Newtonian Mechanics. The study employed a pre-test post-test control group quasi-experimental design on two intact groups of 21 students each of grade 11 from a vocational higher secondary school. The groups were matched based on the pre-test. Investigators found Metacognitive Strategy Instruction effective and significantly contributing to problem solving.

Jadav (2011) constructed and standardized a metacognition inventory for the students of secondary schools of Gujarath state studying in Gujarathi medium. The study was conducted among 1181 students from grade 8, 1072 students from grade 9, and 949 students from grade 10. The investigator found that students of grade 9 and grade 10 were superior to students of grade 8 in the level of metacognition, while there were no significant difference in level of metacognition of grade 9 and grade 10 students. He also found that students of urban area performed better than students of rural area on Metacognition Inventory.

Minikutty and Alka Abbas (2011) conducted a survey on the metacognition of secondary school students. The sample constituted 300 students from various schools of Ernakulum district in Kerala. The study revealed that secondary school students have average metacognition and reflects the need to improve metacognition among students for enhancing achievements and to make them successful thinkers.

Parameswari (2011) investigated the effect of metacognitive orientation to B.Ed. Physical Science trainees on teaching competency and self esteem. The investigator employed single group pre-test post-test design among 44 teacher trainees. The study revealed that metacognitive orientation is a better framework for developing good teaching competency and high self esteem level of student teachers.

Parvathi and Mohaideen (2011) conducted a survey on metacognition of prospective teachers. The survey was among 100 student teachers of Thoothukudi in Tamil Nadu. The investigators found that post graduate student teachers have better metacognition than undergraduate student teachers in the dimension of monitoring. They also found physical science student teachers have more metacognition than the mathematics student teachers in evaluation.

Amutha (2010) developed an e-content with a metacognitive instructional design to empower science teaching competence of B. Ed trainees in the rural areas. After the pre-test post-test control group designed study, she concluded that e-content with a metacognitive instructional design was effective in enhancing the Science Teaching Competence of B. Ed trainees of science in the rural areas.

Rajkumar (2010) conducted an experimental study to check the effectiveness of metacognitive strategies in physics at higher secondary level. The metacognitive strategies were designed with inquiry based learning, cooperative learning and problem based learning. Metacognitive model for achievement in physics at higher secondary level was developed. Pre-test post-test control group design was employed for the study. It was found that the metacognitive awareness had a significant positive influence on achievement in physics.

Shareeja (2010) explored what metacognition is, why it is important and how it develops in children. She argues that teachers need to help children develop metacognitive awareness, and identify the factors which enhance metacognitive development. She considers metacognitive thinking as a key element in the transfer of learning and proposes meta-teaching strategies can help mediate the metacognitive skills of children and stimulate children’s metacognitive thinking.

Visakh Kumar (2010) investigated the effect of metacognitive strategies on classroom participation and student achievement in higher secondary school physics classrooms. A pre-test post-test experimental design involving two intact classrooms of a single school in Thiruvalla in Kerala was employed in the study. The study revealed that the use of metacognitive strategies enhances student achievement and increases participation of students in physics classrooms. The investigator suggested that teachers should allow students to seek understanding by exploring and investigating on their own with teachers as facilitators.

Conclusion of studies on metacognitive strategies in problem solving

There are numerous studies on metacognition in the resent years. Most of these studies confirm that metacognition is a necessary pre-requisite for meaningful learning and conceptual understanding (Case & Gunstone, 2002; Peters & Kitsantas, 2010; Thomas, 2013; Yuruk, Beeth, & Anderson, 2009), developing creativity (Hargrove, 2013; Hargrove & Nietfeld, 2014; Magno, 2010), and problem solving (Demircioglu, Argun, & Bulut, 2010; Jacobse &

Harskamp, 2012; Lubin & Ge, 2012). Though there are very few studies that argue metacognition does not have effect on learning (Demircioglu, Argu, & Bulut, 2010; Meijer, Veenman, & van Hout-Wolters, 2012).

Most studies on the effect of metacognitive training on problem solving are in the domain of mathematics (Jacobse & Harskamp, 2009; Ozsoy, 2011; Schneider & Artelt, 2010). Studies on the effect of metacognition on physics problem solving are rare. In this situation an urge to investigate whether metacognitive strategies enhance students' abilities to solve analogical and novel problems in physics, lead the researcher to develop an instructional strategy following the steps of metacognitive strategies for problem solving. The new instructional strategy so developed was named Metacognitive Strategy Instruction, as it explicitly instructs the steps/ strategy for solving physics problems.

A major challenge in the studies on metacognition seems to be the assessment of metacognitive skills among learners. Researchers widely use two methods to assess metacognitive skills/ activities. They are self-report questionnaires (Downing, Kwong, Chan, Lam, & Downing, 2009; Magno, 2010; Ozsoy, 2011; Taasoobshirazi &Farley, 2013), and think-aloud protocols (Demircioglu, Argun, & Bulut, 2010; Meijer, Veenman, & van Hout-Woulters, 2006; Teong, 2003). Self-report questionnaires are easy to administer, but less valid, while think-aloud protocols are proven valid, but can be administered and objectively evaluated only if the sample size is very small. Researchers (Jacobse & Harskamp, 2012) opine it is better to develop performance based instruments to assess metacognitive skills or strategy use.

Review of studies related to metacognition particularly in India reveals that metacognition is a recent topic in Indian educational research. Some studies compared the level of metacognition in students of different educational levels (Jadav, 2011; Minikutty & Alka Abbas, 2011; Parvathi & Mohaideen, 2011) and found that students of higher levels of education higher levels of metacognition. Some Indian studies investigated the effect of metacognitive strategies on achievement (Gafoor & Shareeja, 2012; Priya, 2013; Rajkumar, 2010; Visakh Kumar, 2010) and teaching competencies (Amutha, 2010; Parameswari, 2011; Parvathi & Mohaideen, 2011). All such studies are equivocal in proclaiming the necessity to enhance metacognitive skills among students.

In the present study investigator assess the use of metacognitive strategy by students using a performance test on representing a problem, planning to solve the problem, implementing plan, and evaluating solution.

Studies on Collaborative Problem Solving in Teaching-Learning Environments

Collaborative group discussions are widely practiced in present day classrooms. This technique seems to have multifaceted effects on students' cognitive skills while accompanying various instructional strategies. Therefore, this section attempts to open up the possibilities of collaborative group discussions and peer interaction and its effect on problem solving. A number of studies on collaboration and peer interaction in the period 1992-2014 are reported in descending chronological order in this section.

Gok (2014) examined the effect of strategic problem solving with peer instruction on college students' performance in physics. The students enrolled in two sections of the physics course were studied. One section was the treatment group and the other section was the control group. Students in the treatment group received peer instruction with systematic problem solving strategies whereas students in the control group received only peer instruction. Data were collected on physics achievement, problem-solving strategies, home-work problems and students' opinions about the instruction. Results indicated that the treatment group students' home-work and achievement test performance as well as their visualizing, solving and checking habits improved relative to the comparison group students, which did not change noticeably. Treatment group students also changed their perspective on solving a problem and found the method helpful to connect the quantitative solution with concepts.

Jordan and McDaniel (2014) investigated how interactions with peers influenced the ways students managed uncertainty during collaborative problem solving in a fifth grade class. The analysis focused on peer responses to individuals' responses to individuals' attempts to manage uncertainty they experienced while they engaged in collaborative efforts to design, built and program robots and achieve assignment objectives. Patterns of peer response were established through the discourse analysis of for five teams engaged in two collaborative projects. Three socially supportive peer responses and two unsupportive peer responses were identified. Peer interaction was influential because students relied on supportive social response to enact most of their uncertainty management strategies. Research suggested conceptualizing collaborative problem solving as a process of negotiating uncertainties can help instructional designers shape task and relational contexts to facilitate learning.

Kim and Tan (2013) explored and documented students responses to opportunities for collective knowledge building and collaboration process in a problem solving process within complex environmental challenges and pressing issues with various dimensions of knowledge and skills. 14 year old middle school students (n=16) and 17 year old high school students (n=16) from two Singapore public institutions participated in an environmental science field study to experience knowledge integration and a decision making process. Students worked on six research topics to understand the characteristics of an organic farm and plan for building an ecological village. Students collected and analyzed data from the field and shared their findings. Their field works and discussions were video recorded, and their reflective notes and final reports were collected for data coding and interpretation. The results revealed that throughout the study, students experienced the need for development of integrated knowledge, encountered the challenges of knowledge sharing and communication during their collaboration, learned how to cope with difficulties and developed mutual relationships such as respect and care for others knowledge and learning.

Zou and Mickleborough (2013) designed a course on engineering grand challenges to promote collaborative problem solving (CPS) skills. The unique component of the design was the students, need to work both within their own team and then collaborate with the other teams to tackle engineering challenges. It was found that the course facilitated development in CPS skills and the process in which two teams develop arguments and integrate the initial ideas to generate a final solution is a critical component. Researchers argue that appropriate scaffolding, explicit training and constant feedback on collaborative processes are important for the skill development.

Gok (2012) assessed students’ conceptual learning of electricity and magnetism and how these conceptions, beliefs about physics, and quantitative problem solving skills would change after peer instruction (PI). The

Conceptual Survey of Electricity and Magnetism (CSEM), and Colorado Learning Attitudes about Science Survey (CLASS) were administered as a pre and post test with Solomon 4 group design to students (N=138) enrolled on freshman level physics course. 14 chapters were taught to students. The analysis of CSEM showed that the treatment group obtained significantly higher conceptual learning gain than the control group. The conceptual understanding and problem solving skills of the students on magnetism were considerably enhanced when PI was conducted. CLASS results for 5 subscales (conceptual understanding, applied conceptual understanding, problem solving general, problem solving confidence, and problem solving sophistication) supported the findings of CSEM.

Nokes-Malach, Meade, and Marrow (2012) conducted an experiment to find the effect of expertise on collaborative problem solving. In the experiment participants with different levels of aviation expertise, experts (flight instructors), novices (student pilots), and non-pilots read flight problem scenarios of varying complexity and had to identify the problem and generate a solution with either another participant of the same level of expertise or alone. The non-pilots showed collaborative inhibition on problem identification in which dyads performed worse than their identified potential for both simple and complex scenarios, whereas novices and experts did not. On solution generation non-pilots and novices performed at their predicted potential with no collaborative inhibition on either simple or complex scenarios. While experts showed collaborative gains, performing above their predicted potential. Researchers concluded that collaborative success is achieved only when there is ‘zone of proximal facilitation’ in which the dyads’ prior knowledge and experience enable them to benefit from both knowledge-based problem solving processes (elaboration, explanation and error correction) and collaborative skills (creating common ground, maintaining joint attention to the task, etc.).

Siegel (2012) generated a framework for conceptualizing metacognition in groups by describing likely components of group metacognition. The framework was based on a study conducted among a group of five pre-service teachers engaged in problem based learning. Data was collected by videotaping the group and facilitator during PBL sessions and also by examining the groups' final paper. Interaction analysis of the group discussions revealed that there are three components of the group metacognition that helped the group members solve the instructional redesign problem: meta-social awareness about other members' expertise, monitoring of understanding, and monitoring of process.

Pazos, Micari, and Light (2010) conducted a multi-phased research study to describe the development of an observation instrument that can be used to assess peer-led group learning based on a classification system for peer-led learning groups. The instrument was used to assess peer-led group learning, based on a classification system for peer-led learning groups. The instrument was used to evaluate small learning groups on two important aspects of group learning, i.e., problem solving and group interaction style. The study provided evidence for the factor structure of the two dimensions using both exploratory and confirmatory factor analysis. It also provided information about the reliability of two scales in terms of Cronbach's alpha coefficient. Data from a large peer-led programme was used to conduct the factor analysis. Results from the factor analysis confirmed that the instrument was actually measuring problem solving approach and group interaction style.

Researchers argue that the instrument may be appealing to faculty members and those running small group learning programmes.

Merrill and Gilbert (2008) suggested that the most effective form of peer interactions in learning communities is for this interaction to take place in the context of a progression of real world problems were learners are engaged in sharing experience early in the sequence, are engaged in discussing and demonstrating cases to each other as a second stage in the sequence, are engaged in collaborative problem solving after the demonstration phase, and are involved in peer-critique and collaborative problem extension later in the process. They also suggest that a progression in the real world problems provides the structure for learners to develop appropriate mental models for solving the problems and that engaging in peer interactions enable learners to tune their mental models to accommodate the variety of processes and solutions that may be appropriate for solving a given class of problems.

Enghag, Gustafsson, and Jonsson (2007) made an in-depth analysis of one group of four students, video-recorded over 135 minutes solving a context rich problem (CRP) to study how students' experiences develop in to physics reasoning. The analysis revealed how the students used exploratory talks to reach consensus about the boundary conditions of the task, how students state the problem more precisely by starting to talk about experiences they have had and use their experiences as arguments, and how individual questions are formulated in a process of meaning making. Researchers concluded that students' personal everyday life experiences develops into physics reasoning during group talk and they argue that more time should be allotted in the physics classroom to solve open-ended physics problems which promote group discussions to enhance understanding physics.

Hausmann, Sande, and VanLehn (2007) conducted an experiment among undergraduates where they compared individuals and pairs learning from state-of-the-art instruction. They found that the dyads solve more physics problems and request fewer hints while solving problems than individuals. They also discovered a new form of self-explanation, where students generated explanations to account for the differences between their solutions and the instructor's.

Harskamp and Ding (2006) compared structured collaborative learning with individual learning environments with Schoenfeld's problem-solving episodes. 99 students from a secondary school in Shanghai participated in the study. They took a pre-test and post-test and had the opportunity to solve six physics problems. Students who learned to solve physics problems in collaboration and students who learnt to solve problems individually with hints improved their problem solving skills compared to those who learnt to solve problems individually without hints. However the researchers did not find an extra effect for students working collaboratively with hints; although they observed that students working collaboratively were more structured than students in the other group.

Yetter, Gutkin, Saunders, Galloway, Sobanskey and Song (2006) used an experimental design to compare the effectiveness of unstructured collaborative practice with individual practice on achievement on a complex well-structured problem solving task. Participants included post-secondary students (N=257) from a liberal arts college serving primarily nontraditional students and from two state universities. Three video-taped instructional procedures were used, including lessons on introductory set theory, a problem solving heuristic, and problem solving modeling. Participants also engaged in active practice. Analysis of variance received significant main effects for treatment condition. Students who practiced individually out-performed those who practiced collaboratively.

Fawcett and Garton (2005) investigated the effect of collaborative learning on children's problem solving ability and whether differences in knowledge status or the use of explanatory language was contributing factors. 100 grade 2 children aged between 6 and 7 years from schools in high socio-economic areas participated in the study. During the experimental phase, children completed a card sorting activity either individually or in same-gender dyads. The dyads consisted of same or different ability children who operated under either a 'talk' or 'no talk' condition. Researchers found that children who collaborated collectively obtained a significantly higher number of correct sorts than children who worked individually. Results also indicated that only those children of lower sorting ability who collaborated with higher sorting ability peers showed a significant improvement in sorting ability from pre-test scores.

Hock and Seegers (2005) investigated the effects of instruction on verbal interactions during collaborative problem solving. Data were collected from vocational education students while they worked collaboratively on open-ended mathematics problems. An experiment was undertaken in two classes in different schools. Two groups of students were videotaped while they tried to solve mathematics problem collaboratively. Analysis of data showed that in both groups, collaboration oriented pattern increased during the school year. It is argued that the approach of gradual implementation of instructional activities that are designed in cooperation with participating teachers is effective in stimulating collaborative problem solving.

Ge and Land (2003) examined the effects of question prompts and peer interactions in scaffolding undergraduate students' problem solving processes in an ill-structured task in problem representation, developing solutions, making justifications and monitoring and evaluating. The quasi-experimental study supplemented by multiple case studies investigated both the outcomes and the processes of student problem solving performance. The quantitative out comes revealed that question prompts have significantly positive effects on student problem solving performance but peer interactions did not show significant effects. However, the qualitative findings did indicate some positive effects of peer interactions in facilitating cognitive thinking and metacognitive skills. Researchers suggested that the peer interaction process itself must be guided and monitored with various strategies to maximize its benefits.

Kramarski and Mevarech (2003) found students participating in cooperative group work expressed their mathematical group work expressed their mathematical ideas in writing more ably than did those who worked alone.

Barron (2000) investigated interactive processes among group partners and the relationship of these processes to problem-solving out comes in two contrasting groups. In one group correct proposals were generated, confirmed, documented and reflected upon. In the other group they were generated, rejected without rationale, and for the most part left undocumented. The study identified two major contrastive dimensions in group interaction viz., the mutuality of exchanges, the achievement of joint intentional engagement, and the alignment of group members' goals for the problem solving processes. A focus on group level characteristics offers a distinctive strategy for examining small group learning and paves the way to understanding reasons for variability of outcomes in collaborative ventures.

Tao (1999) investigated whether and how peer collaboration facilitated students' problem solving in physics. A qualitative physics test was administered to two grade six classes with half of the students in each class randomly assigned to take the test individually and the other half to work in dyads. The abilities of the individuals and dyads were matched such that there was no significant difference between their physics examination grades. The test results showed that dyads performed better than the individuals on each problem and the test as a whole. The rich collaborative talks of the dyads showed that peer collaboration provided students with experiences of co-construction and conflict that was conducive to successful problem solving. Researchers further claimed that students' success in problem solving depended not so much on their ability but on how they interacted and whether and how they invoked the relevant physics principles and strategies.

Heller, Keith, and Anderson (1992) conducted an experiment to investigate the effects of cooperative group learning on a problem solving performance of college students in a large introductory physics course. An explicit problem solving strategy was taught in the course, and students practiced using the strategy to solve problems in mixed-ability cooperative groups. Researchers developed a technique to evaluate students' problem solving performance and determine the difficulty of context-rich problems. It was found that better problem solutions emerged through collaboration than were achieved by individuals working alone. The instructional approach improved the problem solving performance of students at all ability levels.

Conclusion on studies on collaborative problem solving in teaching-learning environments

Over the last decades, much research on peer interaction during problem solving has been conducted. Quantitative experimental designs focusing on cause and effect dominate. There are many strong exponents of collaborative group work and peer interaction who argues that it is necessary to accomplish successful problem solving (Gok, 2014; Heller, Keith, & Anderson, 1992; Merrill & Gilbert, 2008; Zou & Mickleborough, 2013). There are a few (Tao, 1999) who even held peer interaction above individual ability in solving problems. However, there are some researchers who argue that peer interaction as such do not have an extra effect on students' problem solving (Ge, & Land, 2003; Harskamp & Ding, 2006). They advocate that peer interaction itself should be monitored with other strategies to facilitate problem solving. There are very few studies that even advocate individual problem solving as better than collaboration (Yetter, Gutkin, Saunders, Galloway, Sobansky, & Song, 2006)

Under these circumstances of contradicting views on the role of peer interaction on problem solving skill acquisition, the researcher is tempted to investigate whether peer interaction during instruction using the newly developed strategy for enhancing problem solving, viz., Metacognitive Strategy Instruction, would enhance analogical and novel problem solving in physics over Metacognitive Instruction in the absence of peer interaction.

Studies on the Nature of Knowledge Domain needed for Problem solving and the role of concept maps in learning, teaching and problem solving

Conceptual knowledge in the subject domain is a necessary pre-requisite for solving problems. The way this knowledge is presented by the teacher and internalized by the students are also crucial. Therefore this section is devoted to the exploration of concept maps and their possibilities in teaching, learning, and problem solving. A few studies on the nature of knowledge needed for problem solving and the role of concept maps in teaching, learning and problem solving from 1983-2011 are reported in descending chronological order in this section.

Gafoor and Shareeja (2011) validated concept mapping as a tool to assess understanding of physics concepts. The study was conducted among 95 physical science student teachers from five different teacher-training institutions in Kerala, India. The feedback obtained from participants on their experience with concept mapping revealed that if concept maps are used, the very process of evaluation can be informative, engaging, and reinforcing. The investigators propose that both teachers and teacher educators can use concept mapping for re-enforcing knowledge and as an assessment tool.

Daley and Torre (2010) reviewed 35 studies on the use of concept maps in medical education. They found that concept maps function in four main ways: (1) by promoting meaningful learning; (2) by providing an additional resource for learning; (3) by providing instructors to providing feedback to students and (4) by conducting assessment of learning and performance.

Gonzalez, Palencia, Umana, and Galindo (2008) found that using concept maps in problem solving had the most impact on students who came in to the study with the lowest cognitive competence. This indicates that concept mapping represents a method by which teachers can help students who are struggling to learn and perform.

Morse and Jutras (2008) conducted a study where students in cell biology course were divided in to three groups. The control group did not construct concept maps, the second group constructed maps individually, and the third group constructed maps individually and then discussed them in teams that provided both peer and instructor feedback. The study indicated that concept maps without feedback had no significant effect on student performance, whereas concept maps with feedback produced a measurable increase in student problem solving performance and a decrease in failure rates.

Torre, Daley, Stark-Schweitzer, Siddartha, Petkova, and Ziebert (2007) reported that the concept maps allowed for creativity in students by developing a system of thinking that included pattern recognition, the ability to think broadly on topics, and it also allowed for knowledge integration.

Friege and Lind (2006) reported that conceptual knowledge and problem scheme knowledge including situational and procedural knowledge are excellent predictors of problem solving performance. They also reported that conceptual knowledge is typical of low achievers in problem solving whereas problem scheme knowledge is predominantly used by high achievers.

Lavigne (2005) conducted a case study that examined the validity of a particular measure of representation and employed multiple measures to examine whether they provide mutually informative or independent pieces of information. Those measures included (1) concept maps, which measure how individuals represent their content knowledge of a domain as a whole; (2)

problem sorts, which measure how individuals represent a specific aspect of their knowledge on word problems; and (3) structured interviews, which identify the reasons underlying sorting and concept mapping performance. Data from instructors showed that the sorting task was a useful measure of representation when supplemented with instructors' explanations of their rationales. Concept maps assisted in the interpretation of performance on the sorting task. Concept maps and problem sorts were mutually informative, with concept maps providing a broader picture and problem sorts illustrating how particular concepts became salient when applied to a different context.

Laight (2004) designed a study to explore students' attitude towards concept maps as an additional learning resource. Pre-prepared concept maps where integrated in to traditional instruction methods. Later questionnaires were used that asked whether the concept maps were useful and allowed for other comments. A significant majority of students reported that pre-prepared concept maps were useful for their learning. Students also reported being motivated to think more deeply and noted that they gained in understanding of conceptual inter-relationships. Therefore, Laight concluded that pre-prepared concept maps may offer alternative and innovative teaching and learning opportunities and methods in large classes.

Canas, Coffey, Carnot, Felvotich, Hoffman, Feltovich, and Novak (2003) opined that as a resource for learning concept maps allow students to demonstrate their mastery of the concepts associated with a particular body of knowledge. They also opined that concept mapping is a creative activity that fosters reflection on one's own understanding.

Longo, Anderson, and Wicht (2002) tested the efficacy of a new generation of knowledge representation and metacognitive learning strategies called visual thinking networking (VTN). Students who used the VTN strategies had a significantly higher mean gain score on the problem solving criterion test items than students who used the writing strategy for learning science.

Lee, Tang, Goh, and Chia (2001) investigated the effect of cognitive variables viz., concept relatedness, idea association, and problem translating skill in solving problems from different topics and levels. They found that successful problem solving depends on adequate translation of problem statement and relevant linkage between problem statement and knowledge.

Jonassen (2000), and O'Neil and Schacter (1999) suggest that success in problem solving depends on a combination of strong domain knowledge, knowledge of problem solving strategies, and attitudinal components.

Edmondson and Smith (1998) performed a qualitative study that analyzed students' responses to the integration of concept maps as a teaching and learning tool. Almost half of the students agreed that creating a concept map was an effective learning device. As a teaching method concept map provided the teacher with the understanding of the students' errors, and thus allowing the teacher to provide feedback and clarify both content and performance.

Pinto and Zeitz (1997) opined that concept maps can facilitate students' understanding of the organization and integration of important concepts.

Lee (1985) and Lee, Goh, China, and Chin (1996) shows that successful problem solving is related to cognitive variables viz., prior knowledge, concept relatedness i.e., relatedness between concepts that are involved in problem solving, idea association i.e., the ability to associate ideas, concepts, words, diagrams or equations through the use of cues in the statements of the problem, problem translating skill i.e., the capacity to comprehend, analyze, interpret and define a given problem, and prior problem experience i.e., prior experience in solving similar problems.

Schkade and Kleinmuntz (1994) opined that abilities in acquiring information is strongly influenced by organization of information, and skill in combining and evaluating information strongly influenced by the form of representation. They concluded that the way information is externally represented impacts decision making and the ease of carrying out decision making operations.

Ferguson-Hessler and de Jong (1990) collected information on study processes between students who are good problem solvers and students who are not. They found that good and poor performers did not differ in the number of study processes employed, but they differ in the type of processes used. They also found that poor performers pay more attention to declarative knowledge whereas good performers pay more attention to procedural and situational knowledge.

Palumbo (1990) opined that problem solving is a situational and context-bound process that depends on the deep structures of knowledge and experience.

Camacho and Good (1989) studied the difference in the way experts and novices solve problems. Successful solvers perceive the problem by careful analysis and reasoning of the task. They use related principles and concepts to justify their answers, frequent checks of consistency of answers and reason and use better quality of procedural and strategic knowledge. Unsuccessful subjects exhibit many knowledge gaps and misconceptions.

Gorden and Gill (1989) conducted a study on the formation and use of knowledge structure in problem solving domains. They found that well integrated domain knowledge is essential to problem solving. They assumed that learner developed graphs are reflective of learners' underlying cognitive structure. They compared the graphs developed by learners and those by experts and concluded that the similarity of learners' graphs to those of experts are highly predictive of total problem solving score (accounting for over 80% of the variance) as well as specific problem solving activities.

de Jong and Fergurson- Hessler (1986) found that poor problem solvers organized their knowledge in a superficial manner, whereas good problem solvers had their knowledge organized according to problem schemata containing all the knowledge types like, declarative, procedural and situational knowledge required for solving a certain type of problem.

Novak and Gowin (1984) opined that a major purpose of concept mapping is to foster the development of shared meaning between the instructor and the student. As instructors and students discuss, think about and revise concept maps, their learning and shared meaning making processes deepen. They demonstrated how the discussion of concept maps in groups combined with feedback on the maps provided by the instructor, foster students' learning and performance.

Beyer (1984) and DeBono (1983) found that mastery of generalized problem skills did not differentiate well between good and poor problem solvers, and they concluded that knowledge of context was the most crucial feature of problem solving.

Review of literature reveal that concept maps foster the development of meaningful learning, critical thinking and problem solving in the learner (Abel & Freeze, 2006; Daley, Shaw, Balistrieri, Glasenapp, & Piacentine, 1999; Ertmer & Nour, 2007; Hinck, Webb, Sims-Gidden, Helton, Hope, Utley, Savinske, Fahey, & Yarbyough, 2006;

Hsu, &Hsieh, 2005;Kinchin, Cobot, &Hay, 2008; Rendas, Fonseca, & Pinto, 2006; Wilgis & McConnell, 2008). Concept maps are also identified as a valid tool for assessing students' knowledge organization. They seem to aid learning better if students themselves construct the map.

In the present study teacher developed concept maps are used as instructional aides to provide a holistic view of the domain knowledge required for solving problems. Teacher constructs the map as the concepts are introduced and relationships explained during lessons.

Conclusion

Research related to problem solving focused on three major aspects namely, comparison of problem solving behavior differences among expert and novice problem solvers, what contribute to the development of problem solving skills, and teaching problem solving strategies in order to make the novices become expert problem solvers.

The earliest one of these is the comparison of problem solving behavior differences among expert and novice problem solvers (Chi, Feltovich, & Glaser, 1981; de Jong & Ferguson-Hessler, 1986; Dhillon, 1998; Larkin, McDermott, Simon, & Simon, 1980; Priest, & Lindsay, 1992; Reif, & Heller, 1982; Veldhuis, 1990; Zajchowski & Martin, 1993). Investigations on the strategy use of the expert and novice problem solvers reveal that, experts have a tendency of first analyzing the problem qualitatively by depending of the fundamental physics concepts before starting to solve the problems using equations. Whereas novices usually starts to solve the problems using mathematical equations, substituting the given variables, and then investigating other equations where they can substitute the other quantitative variables. Expert problem solvers usually proceed through four phases of analysis when they are faced with a challenging quantitative problem like, conceptual analysis or exploring the problem, strategic analysis or planning for a solution procedure, quantitative analysis or implementing the plan and meta-analysis or reflecting and checking the solution. In typical problem solving instruction, only quantitative analysis is explicitly modeled for the students, leaving them to develop other skills on their own (Gerace & Beatty, 2005).

Later studies that concentrated on what factors contributed to problem solving skills (Robertson, 1990) suggest that the type of knowledge viz., conceptual declarative knowledge, structural knowledge and problem scheme knowledge contribute significantly to problem solving skills (Friege & Lind, 2006). Researchers also emphasis the role of organizing knowledge and finding the relationship between concepts to make them better utilized during problem solving (Beyer, 1984; de Jong & Ferguson-Hessler, 1986; DeBono, 1983; Ferguson-Hessler &de Jong, 1990; Gorden & Gill, 1989; Jonassen, 2000; Lee, 1985; Lee, Goh, China, &Chin, 1996; Longo, Anderson &Wicht, 2002; O'Neil &Schacter, 1999; Palumbo, 1990; Schkade & Kleinmuntz, 1994). Research identifies use of concept maps as an apt method to organize knowledge and express the relationship between concepts. It is an accepted method of teaching and learning (Abel & Freeze, 2006; Daley, Shaw, Balistrieri, Glasenapp, & Piacentine, 1999; Ertmer & Nour, 2007; Hinck, Webb, Sims-Gidden, Helton, Hope, Utley, Savinske, Fahey, & Yarbyough, 2006). In addition to type of knowledge, other factors like working memory, familiarity, epistemic beliefs etc… also seem to influence problem solving. The most important of these is metacognition. Many researchers conclude that the use of metacognitive strategies like planning, executing (implementing), and Checking (evaluating) establish problem solving abilities (Artz & Armour-Thomas, 1992; Brown, Bransford, Ferrara, & Campione, 1983; Horak, 1990; Kramarski & Mevarech, 2003; Muis, 2007; Muis, Gina, & Franco, 2010; Otero, Campanario, & Hopkins, 1992;).

Recent researches on problem solving in physics are directed towards teaching problem solving strategies in order to make the novices become expert problem solvers (Foster, 2000; Heller, Keith, & Anderson, 1992; Huffman, 1997; Larkin & Reif, 1979; Mestre, Dufresne, Gerace, Hardiman, & Touger, 1993; Selcuk & Caliskan, 2008; van Weeren, 1982). Explicit problem solving instruction directly teaches students how to use more advanced techniques for solving problems. Review of literature further reveals that four important factors need special consideration while instructing strategies to develop problem solving skills viz., well organized concept knowledge, proper representation of problem, practice of metacognitive strategies, and peer interaction. In addition to these factors current studies investigate the use of cognitive tools in computer settings during problem solving.

Earlier studies on developing problem solving skills in science were conducted mainly among young children. Later studies on problem solving were extended to high school children (Ding & Harskamp, 2006; Gaigher, Rogan, & Braun, 2007; Pathak, Kim, Jacobson, &Zhang, 2011; Pol, Harskamp, Suhre, & Geodhart, 2008). Current studies on developing problem solving abilities in physics are done in engineering (Bacerra-Labra, Gras-Marti, & Torregrosa, 2012; Hong, Chen, Wong, Hsu, &Peng, 2012) and university undergraduates (Berge & Danielsson, 2012; Mellingsaeter & Bungum, 2014; Stadler & Garcia, 2013; Stadler & Garcia, 2013; Uhden, Karam, Pietrocola, & Pospiech, 2012).

Review of studies related to problem solving particularly in India reveal that most of such studies concentrated on finding relation between problem solving ability and various cognitive and psychological variables (Dutt, 1989; Gill, 1990; Kumari, 1991; Sumangala & Rinsa, 2012; Sumathy, 1994;). Some studies have explored the possibilities of enhancing problem solving skills using existing techniques of teaching without complete success

(Banerji, 1987; Jain, 1982; Manoj Praveen, 2006). In this scenario the investigator feels the necessity to develop an instructional strategy that focuses on the enhancement of problem solving skills and explore its effectiveness.

There are numerous studies on metacognition in the resent years. Most of these studies confirm that metacognition is a necessary pre-requisite for meaningful learning and conceptual understanding (Case & Gunstone, 2002; Peters & Kitsantas, 2010; Thomas, 2013; Yuruk, Beeth, & Anderson, 2009), developing creativity (Hargrove & Nietfeld, 2014; Hargrove, 2013; Magno, 2010), and problem solving (Demircioglu, Argun, & Bulut, 2010; Jacobse & Harskamp, 2012; Lubin & Ge, 2012). Though there are very few studies that argue metacognition does not have effect on learning (Demircioglu, Argu, & Bulut, 2010; Meijer, Veenman, & van Hout-Wolters, 2012;).

Most studies on the effect of metacognitive training on problem solving are in the domain of mathematics (Jacobse & Harskamp, 2009; Ozsoy, 2011; Schneider & Artelt, 2010). Studies on the effect of metacognition on physics problem solving are rare. In this situation an urge to investigate whether metacognitive strategies enhance students' abilities to solve analogical and novel problems in physics, lead the researcher to develop an instructional strategy following the steps of metacognitive strategies for problem solving. The new instructional strategy so developed by the investigators was named Metacognitive Strategy Instruction, as it explicitly instructs the steps/ strategy for solving physics problems.

Review of studies related to metacognition particularly in India reveals that metacognition is a recent topic in Indian educational research. Some studies compared the level of metacognition in students of different educational levels (Jadav, 2011; Minikutty & Alka Abbas, 2011; Parvathi & Mohaideen, 2011) and found that students of higher levels of education higher levels of metacognition. Some Indian studies investigated the effect of metacognitive strategies on achievement (Gafoor & Shareeja, 2012; Priya, 2013; Rajkumar, 2010; Visakh Kumar, 2010) and teaching competencies (Amutha, 2010; Parameswari, 2011; Parvathi & Mohaideen, 2011). All such studies are equivocal in proclaiming the necessity to enhance metacognitive skills among students.

A major challenge in the studies on metacognition seems to be the assessment of metacognitive skills among learners. Researchers widely use two methods to assess metacognitive skills/ activities. They are self-report questionnaires (Downing, Kwong, Chan, Lam, & Downing, 2009; Magno, 2010; Ozsoy, 2011; Taasoobshirazi &Farley, 2013), and think-aloud protocols (Demircioglu, Argun, & Bulut, 2010; Meijer, Veenman, & van Hout-Woulters, 2006; Teong, 2003). Self-report questionnaires are easy to administer, but less valid, while think-aloud protocols are proven valid, but can be administered and objectively evaluated only if the sample size is very small. Researchers (Jacobse & Harskamp, 2012) opine it is better to develop performance based instruments to assess metacognitive skills or strategy use.

In the present study investigator assess the use of metacognitive strategy by students using a performance test on representing a problem, planning to solve the problem, implementing plan, and evaluating solution.

Over the last decades, much research on peer interaction during problem solving has been conducted. Quantitative experimental designs focusing on cause and effect dominate. There are many strong exponents of collaborative group work and peer interaction who argues that it is necessary to accomplish successful problem solving (Gok, 2014; Heller, Keith, & Anderson, 1992; Merrill & Gilbert, 2008; Zou & Mickleborough, 2013). There are a few (Tao, 1999) who even held peer interaction above individual ability in solving problems. However, there are some researchers who argue that peer interaction as such do not have an extra effect on students' problem solving (Ge, & Land, 2003; Harskamp & Ding, 2006). They advocate that peer interaction itself should be monitored with other strategies to facilitate problem solving. There are very few studies that even advocate individual problem solving as better than collaboration (Yetter, Gutkin, Saunders, Galloway, Sobansky, & Song, 2006)

Under these circumstances of contradicting views on the role of peer interaction on problem solving skill acquisition, the researcher is tempted to investigate whether peer interaction during instruction using the newly developed strategy for enhancing problem solving, viz., Metacognitive Strategy Instruction, would enhance analogical and novel problem solving in physics over Metacognitive Instruction in the absence of peer interaction.

Review of literature also reveals that concept maps foster the development of meaningful learning, critical thinking and problem solving in the learner (Abel & Freeze, 2006; Daley, Shaw, Balistrieri, Glasenapp, & Piacentine, 1999; Ertmer & Nour, 2007; Hinck, Webb, Sims-Gidden, Helton, Hope, Utley, Savinske, Fahey, & Yarbyough, 2006; Hsu, &Hsieh, 2005; Kinchin, Cobot, &Hay, 2008; Rendas, Fonseca, & Pinto, 2006; Wilgis & McConnell, 2008). Concept maps are also identified as a valid tool for assessing students' knowledge organization. They seem to aid learning better if students themselves construct the map.

In the present study teacher developed concept maps are used as instructional aides to provide a holistic view of the domain knowledge required for solving problems. Teacher constructs the map as the concepts are introduced and relationships explained during lessons.

Informed by the review of literature, the investigators of the present study, Gafoor & Shareeja (2012) developed a metacognitive strategy instruction for enhancing problem solving skills in physics that incorporated the ideas of organizing knowledge through concept maps, diagrammatic representation of problem, and use of metacognitive strategies/ skills. A pilot study was conducted to find the effect of this newly developed Metacognitive Strategy Instruction on solving problems in Newtonian Mechanics. The study employed a pre-test post-test control group quasi-experimental design on two intact groups of 21 students each of grade 11 from a vocational higher secondary school. The groups were matched based on the pre-test. Investigators found Metacognitive Strategy Instruction effective and significantly contributing to problem solving.

After the pilot study, the researchers felt that the instructional strategy could be better if they incorporated analogical problems for the students to try out after each problem. This is also supported by other researches in problem solving (Atkinson, Derry, Renkl, & Wortham, 2000; Hausmann, Sande, & Vanheln, 2007).

Inspired by the review of literature and pilot study, the investigators of the present study modified the metacognitive strategy instruction for enhancing problem solving skills in physics that incorporated the ideas of organizing knowledge through concept maps, diagrammatic representation of problem, and use of metacognitive strategies/ skills and provision for analogical problem solving. Students of grade 11 were instructed using this new strategy to solve problems from Newtonian mechanics. The effect of the strategy was then explored in a classroom facilitating peer interaction and that which does not encourage peer interaction. The effect of the newly developed strategy on enhancing analogical problems (problems similar to those solved in the classroom and from the same content domain) and the transfer of skills in problem solving to other areas of physics are investigated. Results are analyzed and suggestions made.

Chapter III

METHODOLOGY

- *Variables*
- *Design of the Study*
- *Tools Used in the Study*
- *Sample*
- *Statistical Analysis*

The objective of this study was to develop and test the effectiveness of an instructional strategy to foster problem solving skills in physics among higher secondary school students. The first part of the objective required development of an Instructional Strategy to Enhance Problem Solving. Second aspect of the objective is to test the effectiveness of the instructional strategy to foster problem solving skills in physics. This part of the study is designed to answer the following research questions.

1. Can Metacognitive Strategy Instruction [Peer Interacting Metacognitive Strategy (PIMS) Instruction and Metacognitive Strategy (MS) Instruction] significantly improve Analogical Problem Solving ability in Physics among Higher Secondary School Students? If so, can Peer Interacting Metacognitive Strategy Instruction develop analogical problem solving ability better than Metacognitive Strategy Instruction?

2. Can Metacognitive Strategy Instruction [Peer Interacting Metacognitive Strategy (PIMS) Instruction and Metacognitive Strategy (MS) Instruction] significantly improve Problem Solving Skills in Physics among Higher Secondary School Students?, if so can Peer Interacting Metacognitive Strategy Instruction develop problem solving skills in physics better than Metacognitive Strategy Instruction?

3. Can Peer Interaction [Peer Interacting Metacognitive Strategy (PIMS) Instruction] significantly improve the Use of Metacognitive Strategies in Problem Solving of Higher Secondary School Students (over Metacognitive Strategy Instruction)?

4. Which component skills in metacognitive strategy of problem solving viz.,

    i. Representing the problem
    ii. Planning the solution
    iii. Implementing the plan and
    iv. Evaluating the solution

    contribute significantly to the problem solving skills in physics in students instructed on Metacognitive Strategy?

Hence, this study adopts a quasi- experimental design. The important elements of the research design like variables, samples selected for the study, tools used, teaching material and the statistical analyses employed to analyse data are described in this chapter. For obtaining a summery view of the methodology at a glance, the outline of the total procedure is given in figure2.

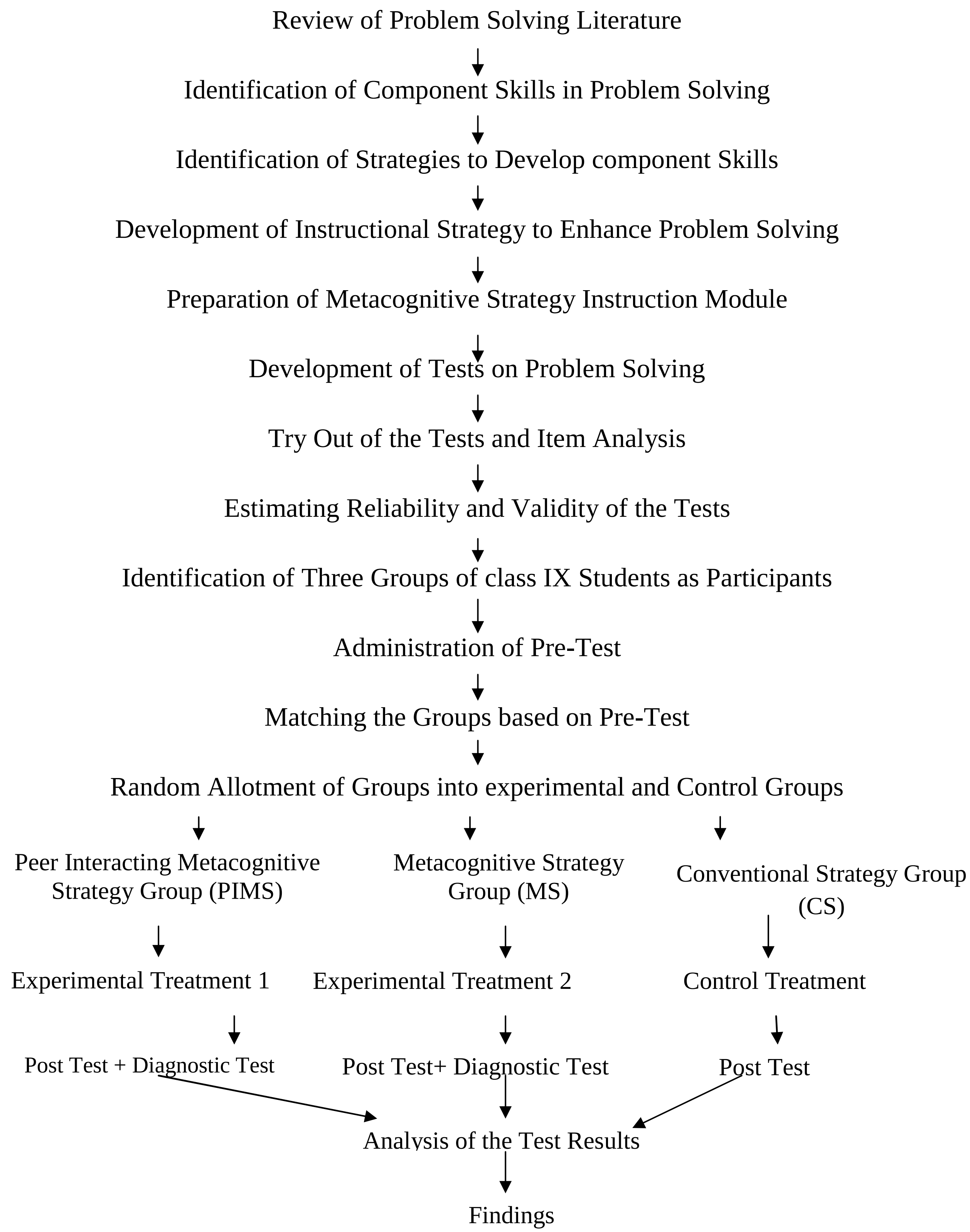


Figure 2: An Outline of the Study

In order to have a more structured view of the design, the variables of the study are described, before taking up a detailed account of each segment of the study.

Variables of the Study

The Pre-Test_ Post-Test Control Group Design of this study employed independent variables, dependent variables and control variable. These variables were the following.

Independent Variable

Independent variable in this study is the instructional strategy used to inculcate problem solving ability in mechanics. Independent Variable in this study has the following three levels.

1. Metacognitive Strategy (MS)

This is a four phased strategy for fostering component skills in problem solving where in students solve problems independently under the guidance of the teacher.

2. Peer Interacting Metacognitive Strategy (PIMS)

This strategy, also in four phases, focuses on enhancing students' problem solving in homogeneous groups under the guidance of the teacher.

3. Conventional Strategy

This strategy with three phases also focuses on problem solving, but students work individually under the guidance of teacher.

Dependent Variables

This study examines the effectiveness of an instructional strategy to foster problem solving skills in physics among higher secondary school students. Hence problem solving ability in physics is the dependent variable. Specifically the study employs the following seven measures to point out effectiveness of the independent variable to foster problem solving skills in students.,

1. Analogical Problem solving Ability

This refers to the ability to solve problems in mechanics using strategies similar to those practised in classroom.

2. Problem Solving Ability in Physics

This refers to the ability to solve novel problems from areas of physics other than mechanics that the students have not previously solved in classroom.

3. Use of Metacognitive Strategies for Problem solving

This refers to the total (plus component- wise) skills in problem solving developed in the students because of instruction using the three select strategies. Each of the four component skills are further taken as dependent variables, resulting in four sub variables, namely,

i. Representing the Problem situation
ii. Planning the Solution
iii. Implementing the Plan
iv. Evaluation of Solution

Control Variable

All the three groups namely PIMS, MS and CS were matched based on their Previous Problem Solving Ability. Hence the control variable in this study is the previous problem solving ability of pupils. All the three groups were instructed by the investigator and hence teacher factor is considered constant.

Experimental Design

Metacognitive Strategy Instruction is viewed at three levels, viz., Peer Interacting Metacognitive strategy (PIMS), Metacognitive Strategy (MS), and Conventional strategy, all of which focus on fostering problem solving skills in physics. This study limits itself to the area of mechanics. MS and PIMS are four phased, while the conventional strategy is three phased. The first three phases in all the three strategies are similar. The fourth phase in MS involves metacognitive analysis of the previous phases gone through and solution of an analogical problem, which is done individually. In PIMS, the fourth phase is similar to that of MS except the fact that students are grouped and they perform the activities in homogeneous groups.

In order to test the effectiveness of the three strategies in fostering problem solving skills in physics, an experimental procedure was used, with a quasi-experimental design.

Non-Equivalent Pre-Test_ Post-Test Control Group Design used in this study can be depicted as follows:

G_1 : $O_1 X_1 O_4 O_7 O_{10}$

G_2 : $O_2 X_2 O_5 O_8 O_{11}$

G_3 : $O_3 C_1 O_6 O_9$

O_1, O_2 and O_3 are the Pre-tests on the dependent variable [Previous Problem Solving Ability in Physics]

O_4, O_5 and O_6 are the Post-tests, viz., Analogical Problem Solving Agility in Physics.

O_7, O_8 and O_9 are the Post tests, viz., Problem Solving Skills in Physics.

O_{10}, and O_{11} are the Post tests on the Use of Metacognitive Strategies in Problem Solving involving Component skills (representing the problem, planning the solution, implementing the plan, evaluating the solution)

G_1 is the First Experimental Group (PIMS group)

G_2 is the Second Experimental Group (MS group)

G_3 is the Control Group

X_1 is the Application of First Experimental Treatment (Peer Interacting Metacognitive Strategy)

X_2 is the Application of Second Experimental Treatment (Metacognitive Strategy)

C_1 is Application of Control Treatment (Conventional Strategy)

All the three groups are matched based on their previous problem solving ability.

Tools Used for the Study

The tools were developed and used to quantify the dependent and control variables. In total, four Tests on Problem Solving especially in the field of mechanics to be administered at different stages of the study were developed. Two of these tests are parallel and were used as the pre-test and post-test of problem-solving ability. Thus, the three separate tests developed were the following.

1. Tests of Problem-Solving Ability (Two Parallel Forms; Previous Problem Solving Ability, and Analogical Problem Solving Ability,).
2. Test on Problem Solving Skills in Physics.
3. Test on Component Skills in Problem Solving (Use of Metacognitive Strategies in Problem Solving)

This test consists of four sub-tests, viz.,

1) Test on the Ability to Represent Problem situation
2) Test on the Ability to Plan Problem Solving Procedure
3) Test on the Ability to Implement Problem Solving Procedure
4) Test on the Ability to Evaluate Solution to a Problem

The development of each of these tools is explained in detail in the following section. General pattern followed for the development of these tests was reviewing the literature on the related area, identifying the cognitive task/ content area, deciding upon the weightage to be given to each area, deciding the item format, deciding the number of items/ duration of the test, developing a table of specification, item writing, item editing by experts, tryout, item analysis, selection of final set of items, and establishing the indices of reliability and validity of the test. For all the tests, try out sample was randomly selected as 112 class IX students from two higher secondary schools in Kozhikode district. The pilot-tests were conducted in the middle term of the academic year, so that sample students were already exposed to the contents covered in the tests via regular class room instruction and they can attempt to solve the problems in the tests.

The development of each of the tests is detailed below.

1. Tests of Problem solving Ability in Physics.

Two parallel tests were used as the pre-test and post-test of problem-solving ability, in order to prevent the testing effect on the outcome. The content area of these parallel tests was limited to mechanics. The test was developed as a whole test and then was split into two equal halves. This was done based on the item discrimination, and item difficulty. Another test of Problem Solving Ability in Physics covering all important areas of Physics was also prepared to examine the transfer value of what is learn on the basis of study of unit on mechanics to the other units in Physics. While developing the test the following procedure was adopted.

a) Reviewing the literature on test on problem solving ability and identifying the tasks to be involved in test items

In traditional classrooms, teachers often assess students based on their abilities to recall information or comprehend simple relationships among ideas. But in a classroom based on problem solving, students are engaged in activities that extend far beyond recalling information and understanding simple relationships. Instead they are engaged in collaboratively analysing, researching and solving problems. Traditional tests are therefore not useful tools for measuring student's success with these complex activities (Darling-Hammond & Snyder, 2000).

Campione (1989) states that "successful learners can reflect on their own problem solving activities, have available powerful strategies for dealing with novel problems, and oversee and regulate those strategies efficiently and effectively". They also indicate that assessing this type of learning requires dynamic rather than static measures. Dynamic measures are better predictors of gains in performance and are significantly diagnostic than learning scores from static tests.

The cognitive tasks involved in the solution of problems are explained below.

i) Application of a Single Equation

Here the students are required to read the problem situation, identify the key terms, ie., the physical quantities given and those that is to be determined, identify the principle/ equation connecting the known and unknown physical quantities, rearrange the equation to obtain a solution for the problem and then substitute the values and mathematically solve the problem.

ii) Application of more than one equation

Now all the physical quantities required to solve the equation is not directly specified in the problem. The students need to obtain values for these physical quantities using appropriate principles/ equations following the previous procedure and then apply them in the final equation to solve the problem.

iii) Application of Equations + Additional Assumptions

Here the unknown physical quantities required to solve the problem can not be determined from other principles/ equations. The examinees need to go through the previous cognitive tasks and in addition make certain assumptions appropriate to the problem situation.

Example 1: If a stone is thrown upwards,

Assumption 1: The time taken for upward motion will be equal to the time taken for downward motion

Assumption 2: The velocity of the stone at the topmost point is zero.

Example 2: If a helicopter flying in horizontal direction drops a bomb,

Assumption 1: The initial vertical velocity of the bomb is zero.

Assumption 2: the horizontal acceleration of the bomb is zero in its downward flight.

Assumption 3: the vertical acceleration of the bomb is 9.8 m/s^2.

iv) Application of Equations + Unit Conversion

Now the values of certain physical quantities required to solve the problem will be provided in different systems of units. So before using the previous cognitive tasks, the students need to unify all the units in to a single system, usually SI system by multiplying with appropriate conversion factors.

Example 1: Speed of a car given in km/h should be converted to m/s before using it in equation.

Example 2: Mass of a body given in grams should be converted to kg before substituting its value in an equation

Evidently, the cognitive tasks in problem solving are cumulative in nature. The number of test items /problems from each content area demanding prescribed cognitive tasks given in Table 1 was finalised after item analysis.

1. Test of Problem Solving Ability (Form A and Form B)

b) Identifying the weightage to content domain

The important content topics to be covered by the test were ‘Motion in a Straight Line’, ‘Motion in a Plane’ and ‘Newton’s Laws of Motion’.

c) Deciding the item formats

An objective type (multiple choice), norm referenced test was prepared on the broad objective of measuring domain specific problem solving ability of students in mechanics.

d) Preparing table of specification

As the Test of Problem solving Ability has two parallel forms and each of the final Form was to consist of 15 problems from mechanics, in total 30 items were required. Taking into consideration, the time involved for students to complete the items that require problem solving, 42 problems from the units of mechanics in higher secondary physics curriculum were planned for the draft test. As all good achievement tests should be based on either explicit or implicit objectives or topics reflected in table of item specifications, the test blue print representing the content and cognitive tasks involved is shown in Table 5.

Table 5

Blue Print of Test of Problem Solving Ability Showing the Number of Items from Select Content Area by Cognitive Tasks

Content Area	Cognitive Tasks (Applying)				Number of Items
	a single equation	more than one equation	equations + additional assumptions	equations + unit conversions	
Motion in a straight line.	3	3	2	2	10
Motion in a plane	1	2	4	3	10
Newton's laws of motion	2	2	3	3	10
Total	6	7	9	8	30

Table 5 represents the plan of the test to measure problem solving ability in physics, especially in the field of mechanics.

Item writing

The items were developed as per the table of specification. More than required number of items was prepared from each content area and on the different cognitive tasks, such that the final test, could be assembled in tune with the table of specification. The Test of Problem Solving Skills in Physics in its draft form is appended as Appendix A1.

Scoring

After administering the test to 112 students in two different Higher Secondary schools in Kozhikode district, the items were scored. Each correct response were given score 1. Each item that was not attempted and each incorrect response were given score 0. After scoring, the items were analysed to find their discriminating power and difficulty index. The scores were also used to estimate the reliability of the tests.

Item Analysis

The steps used for item analysis in the present study are:

- All item scores are first orderly arranged from highest to the lowest of total scores.
- The sum of the numbers of examinees who gave the correct responses for each item were divided by the total number of examinees and then multiplied by 100. The result is the index of difficulty or P- value.
- 27% of the students with the highest scores were selected and named the upper group. Similarly, 27% of the students with the lowest scores were selected and named the lower group.
- For each item, number of examinees who gave correct response in the upper group and in the lower group were counted separately.
- Subtracted the lower group count from the upper group count and divided this difference by the number of examinees in one of the group (either upper or lower group, both are of the same size). The result obtained is the index of discrimination or D-value.

Items were selected for the achievement test on the basis of P-value or the indices of difficulty. The normal curve can be taken as a guide in the selection of difficulty indices. Thus, 50% items must have difficulty between 0.25 and 0.75. Similarly, 25% indices must be larger than 0.75 and 25% must be smaller than 0.25. This criterion was adopted in the present study while selecting the items for the test on the basis of P-value. Item wise indices of difficulty and discrimination are appended as Appendix 3.

The difficulty index (P-value) of the items selected after item analysis is shown in Table 6.

Table 6

Difficulty Index of Test Items in the Test of Problem Solving Ability

Sl No:	Difficulty Index (P-value)	No: of items
1	P<0.25	8 items (26.5%)
2	0.25<P<0.75	16 items (53%)
3	P>0.75	6 items (20%)

Table 6 reveals that difficulty index of the test items approximately fits the normal curve.

In the present study only items with D-value greater than 0.30 was selected. The discriminating power (D-value) of items selected after item analysis is shown in Table 7.

Table 7

Discriminating Power (D-value) of Items in the Test of Problem Solving Ability

Sl No:	Discriminating Power (D-value)	No: of Items
1	D>0.50	11
2	0.40<D<0.50	9
3	0.30<D<0.40	10
4	D<0.30	0

Table 7 shows that out of 30, 20 items (67%) are very good and 10 items (33%) are reasonably good. No items are marginal or poor.

After item analysis the items were ranked as per D-value. Odd items were taken as the problems/items of the Test of Previous Problem Solving Ability in Physics (Form A - Pre-test). The final form of pre-test is appended ad Appendix A4. The selected even items were taken as the problems/items of the Test of Analogical Problem Solving Ability in Physics (Form B - Post-test). The final form of post-test is appended as Appendix A5.

Reliability and Validity

Since the study attempts to construct two parallel tests namely ‘Test of Problem Solving Ability (Form A- Pre – Test)’ and ‘Test of Problem Solving Ability (Form B – Post – Test)’, parallel forms reliability (also called index of equivalence) was determined. The two tests were administered to the same group. Items of ‘Test of Problem Solving Ability (Form A – Pre – Test)’ were taken as the odd numbered items in the test form and items of ‘Test of Problem Solving Ability (Form B – Post – Test)’ were taken as the even numbered items. The Pearson's coefficient of correlation, r between the total scores of the two parallel tests are 0.89.

While preparing the test items, for each item in Form A a parallel item from the same content area and requiring the same cognitive task was made for Form B. All items intended for form A was taken as odd numbered and all items intended to be in form B was taken as even numbered in the combined test form. The Pearson's coefficients of correlation for parallel-paired items are given in Table 8.

Table 8

Correlation between Matched Items in Form A and Form B of Test of Problem Solving Ability

Pairs of items in the combined test form	Pearson's r
Item 1, Item 2	0.92
Item 3, Item 4	0.93
Item 5, Item 6	0.83
Item 7, Item 8	0.86
Item 9, Item 10	0.74
Item 11, item 12	0.86
Item 13, Item 14	0.79
Item 15, Item 16	0.79
Item 17, Item 18	0.86
Item 19, item 20	0.75
Item 21, item 22	0.78
Item 23, Item 24	0.79
Item 25, Item 26	0.79
Item 27, Item 28	0.82
Item 29, Item 30	0.78

According to Kuder and Richardson (1937), to assess equivalent forms reliability both forms should be administered to the same examinees at the same time. Using test scores from both forms, high coefficients (0.80's or

0.90's) indicates that scores from either forms can be used interchangeably. Table 8 shows that the coefficients of correlation between the paired items are about 0.8 or above. Therefore, they can be used interchangeably. Further the Pearson's correlation for odd-even items is found to be r=0.89. This means the tests are reliable and parallel or equivalent.

Validity is the extent to which the instrument measures what it purposes to measure. Content validity pertains to the degree to which the instrument fully assesses or measures the construct of interest. The present tool intends to measure problem solving ability of students in the domain of mechanics. So different problems from the content area specified in the blueprint given in table 1 are included to ensure content validity.

Face validity of the test is established by review of the instrument by two experienced physics teachers from government higher secondary schools of Kerala.

While carrying out the test all required equations, that the students should otherwise memorise, were displayed. This was to ensure that the instrument measures the problem solving skills of students and their rote memorisation capacity is not a hindrance to problem solving. By setting such a test environment congenial for student performance, ecological validity was ensured by providing the materials they were familiarised within classroom problem situations (Brewer, 2000).

2. Test of Problem Solving Skills in Physics

Test of problem solving skills in physics consists of 15 problems from different areas of physics. In order to construct it 20 problems from the units Work Energy and Power, System of Particles and Rotational Motion, Gravitation, Mechanical Properties of Solids and Mechanical Properties of Fluids in Higher secondary physics curriculum were prepared. Out of these 20 problems, 15 were selected after pilot test, followed by item analysis.

Test of Problem Solving Skills in Physics is an objective type (multiple choice), norm referenced test. The test blue print representing the content and cognitive tasks involved is shown in Table 9.

Table 9

Blue Print of the Test of Problem Solving Skills in Physics Showing the Number of Items from Select Content Area by Cognitive Tasks

	Cognitive Tasks (Applied)				
Content	a single equation	more than one equation	equations + additional assumptions	equations + unit conversions	Number of Items
Work Energy and Power	1	0	2	1	4
Rotational Motion	0	1	2	1	4
Gravitation	0	1	2	0	3
Properties of Solids	1	0	2	1	4
Properties of Fluids	0	1	2	2	5
Total	2	3	10	5	20

Table 9 represents a blue print of the test to measure the problem solving skills in those areas of physics, which was not covered as a part of the experimental treatment by the investigator. The topics were already taught as part of their regular classroom instruction.

The cognitive tasks involved in the solution of problems are presented as the column headings. They are similar to those explained before. The test of Problem Solving Skills in Physics in its draft form and final form are appended as Appendix B1 and Appendix B4 respectively.

Scoring

After administering the test to 112 students in two different Higher Secondary schools in Kozhikode district, the items were scored. Each correct response were given score 1. Each item that was not attempted and each incorrect response were given score 0. After scoring, the items were analysed to find their discriminating power and difficulty index. The scores were also used to estimate the reliability of the tests.

The number of test items/problems from each content area demanding prescribed cognitive tasks given in Table 9 were finalised after item analysis. The steps followed for item analysis were similar to those explained already for tests of problem solving ability (Form A and Form B). Item wise indices of difficulty and discrimination for the Test of Problem Solving Skills in Physics are appended as Appendix B3.

The difficulty index (P-value) of the items selected after item analysis is shown in table 10.

Table 10

Difficulty Index of Test Items in the Test of Problem Solving Skills in Physics

Sl No:	Difficulty Index (P-value)	No: of items
1	$P<0.25$	3 items (20%)
2	$0.25<P<0.75$	10 items (66%)
3	$P>0.75$	2 items (14%)

Table 10 reveals that difficulty index of the test items approximately fits the normal curve.

The discriminating power of items selected after item analysis is shown in table 11.

Table 11

Discriminating Power (D-value) of Items in the Test of Problem Solving Skills in Physics

Sl No:	Discriminating Power (D-value)	No: of Items
1	D>0.50	7
2	0.40<D<0.50	4
3	0.30<D<0.40	4
4	D<0.30	0

Table 11 shows that out of 15 items, 11 are very good and 4 items are reasonably good. No items are marginal or poor.

Reliability and validity

The reliability across test items or internal consistency was determined by administering the test to a group of 112 students in government higher secondary schools of kerala. The investigator then found the split half reliability by splitting the test in to two parts systematically. ie., all odd numbered items were taken as one part and all even numbered items were taken as the other part. The correlation between the parts of the index of consistency is found to be 0.74 (N=112). According to Nunnally and Bernstein (1994) if the index of internal consistency is 0.70 or higher, the test can be considered 'good' or 'adequate'. Since the internal consistency index for the Test of Problem solving Skills in Physics is found to be 0.74, it can be considered as an adequate tool.

The present tool as the name indicates attempts to measure, the general skills in solving well structured academic problems in physics. The content validity or the degree to which the instrument fully assess or measures this construct is ensured by including in the test, problems or items from all the domains of physics to which the students are exposed/taught till the time of the experiment. Attempt is also made to include different cognitive tasks that may be required while solving a well-structured academic problem as in the blue print given in Table 9.

Face validity of the test is established as in the case of the previous tool by review of the tool by two experienced physics teachers from government higher secondary schools of Kerala. Further to avoid the effect of rote memorisation capacity of students, all the equations that the students may require while solving the problems was displayed during the administration of the test.

3. Test on Component Skills in Problem Solving (Use of Metacognitive Strategies in Problem Solving)

Diagnostic assessments are utilised to determine the current knowledge level of a student. It involves testing to learn if a certain standard has been achieved and provides valuable feedback to the instructor. However diagnosis is performed differently for different purposes. In the present study the investigator conducts a diagnostic test to identify whether the students are using various steps in the problem solving procedure which are explicitly taught to them while solving an academic problem. In other words, this study requires determining how far the students developed the proficiency in using various component skills during problem solving. The study requires information on which of the two experimental groups has developed better proficiency in diverse tasks/ component skills in the process of problem solving. The component skills involved in the problem solving procedure that are explicitly taught to the students are:

1) Represent Problem situation
2) Plan Problem Solving Procedure
3) Implement Problem Solving Procedure
4) Solution to a Problem

Item Selection for test on Component Skills in Problem Solving (Use of Metacognitive Strategies in Problem Solving)

Item selection for the diagnostic test is accomplished by predetermining a set of items based on the different tasks involved in the process of problem solving. The content area involved is the same as that for the Test of Problem Solving Ability in Physics (Form A and Form B) discussed before.

The blue print given in Table 12 represents the distribution of items from various content areas among diverse component skills involved in problem solving procedure.

Table 12

Blue Print of the Test on Component Skills in Problem Solving (Use of Metacognitive Strategies in Problem Solving) Showing the Number of Items from Select Content Area by Component Skills

Content	Component Skills in Problem Solving				Total
	Representing	Planning	Implementing	Evaluating	
Motion in a straight line.	1	2	2	1	6
Motion in a plane	3	1	2	2	8
Newton's laws of motion	1	2	1	2	6
Total	5	5	5	5	20

Table 12 represents a blue plan of the diagnostic test on component skills in problem solving in physics, particularly in the domain of mechanics. The important content topics covered are 'Motion in a Straight Line', 'motion in a Plane' and 'Newton's laws of Motion' as listed in the first column.

The component skills required to solve problems are presented as the column headings of the next four columns. Each of these component skills further involves various tasks as discussed in the next section.

The the diagnostic test on component skills in problem solving is divided in to four sub-tests, viz.,

1) Test on the Ability to Represent Problem situation
2) Test on the Ability to Plan Problem Solving Procedure
3) Test on the Ability to Implement Problem Solving Procedure
4) Test on the Ability to Evaluate Solution to a Problem

This is done to determine the proficiency of students in each of these component skills separately. Each of these sub-tests is discussed in detail below.

1) Test on the Ability to Represent Problem situation

In formal educational contexts, students have to solve well-structured problems that require the application of a finite number of concepts, rules and principles; possess a well defined initial state, a known goal state and constrained set of logical operators; present all elements of the problem to the learners. Solving such problems depend on how the problem is represented. Proper representation of the problem and the domain knowledge required to solve it are crucial.

The inability of students to transfer well-structured problem solving skills to novel problems is because of the inadequate representation of the knowledge that is required to solve problems (Simon, 1978). Hence, problem representation is central to problem solving.

Experts are better problem solvers than novices because they construct richer, more integrated representations of problems than do novices (Chi, Feltovich & Glaser,1981; de Jong & Ferguson-Hessler, 1991; Larkin 1983). Their representations integrate domain knowledge with problem types (Chi, Feltovich & Glaser, 1981).

Relying exclusively on a quantitative form of representation restricts students understanding of the problem and its relationship to domain knowledge (Hegarty, Mayer & Monk, 1995). Ploetzner, Fehse, Kneser and Spada (1999) showed that when solving physics problems, qualitative problem representations are prerequisites to learning quantitative representations. Representing problem situation also guide further interpretation of information. This information can assume three different forms: numerical, verbal, or pictorial.

Discussion above shows that proper representation of a problem situation results in:

i. Further interpretation of information
ii. Inferring quantitative representations/ equations
iii. Elicite numerical values for certain physical quantities
iv. Provide pictorial representation of data

The items in the sub-test 'Test on the Ability to Represent Problem situation' are designed to assess whether students are able to perform these functions of problem representations.

Table 13 shows the distribution of items from different content areas corresponding to these functions.

Table 13

Content wise Distribution of Items in the Sub Test 'Test on Ability to Represent Problem Situation'

Content	Representing Problem Situation				Total
	Interpretation of Information	Inferring Equations	Values of Physical quantities	Pictorial Representation of Data	
Motion in a straight line.	0	0	0	1	1
Motion in a plane	1	1	1	0	3
Newton's laws of motion	0	0	0	1	1
Total	1	1	1	2	5

Table 13 shows that there are items in the sub test to assess the ability of students to perform all the above mentioned functions of the component skill ‘representing a problem Situation’.

2) Test on the Ability to Plan Problem Solving Procedure

Learners solve most overt problems in maths and sciences by identifying key concepts and values in a short scenario, selecting the appropriate algorithm, applying the algorithm to generate a quantitative answer, and then checking their responses. Therefore once a problem is properly represented and additional inferences on problem situation are drawn, the next step is planning a problem solving procedure.

Planning a problem solving procedure involves:

i. Identifying the variables, those are explicitly specified and those are required to find in the problem.
ii. Identifying relevant principles and equations, which lead to the solution of the problem.
iii. Making additional assumptions required to solve the problem.
iv. Generating or deriving those equations which are not explicit, but necessary for solving the problem.

The items in the sub test ‘Test on the Ability to Plan Problem Solving Procedure’ are designed to assess the proficiency of students to perform these tasks.

Table 14 shows the distribution of items from different content areas corresponding to these tasks.

Table 14

Content wise Distribution of Items in the Sub Test 'Test on the Ability to Plan Problem Solving Procedure'

Content	Planning Problem Solving Procedure				Total
	Identifying Variables	Identifying Principles	Additional Assumptions	Deriving Equations	
Motion in a straight line.	1	1	0	0	2
Motion in a plane	0	0	1	0	1
Newton's laws of motion	1	0	0	1	2
Total	2	1	1	1	5

The table shows that there are items in the sub test to assess the proficiency of students to perform all the above-mentioned tasks related to planning a problem solving procedure.

3) Test on The Ability to Implement Problem Solving Procedure

Mathematics, commonly referred to as "the language of science" is an essential prerequisite to the study of physics. A typical physics problem requires students to use their understanding of mathematical concepts to set up and then solve it.

Unfortunately, in physics problem solving students appear to have trouble with solving algebraic equations, computing values when it deals with powers of tens, and rearranging equations to yield value of a particular variable etc. Such troubles often act as a hindrance while implementing problem-solving procedure. Such troubles occurs because, many students have only developed an algorithmic understanding of the problem solving procedure. But, problem solving expertise include opportunistic blending of formal and mathematical reasoning while manipulating equations (Fauconnier & Turner,2003; Sherin, 2001).

The ability to implement problem-solving procedure refers to how students use the equations after their selection. In other words, it refers to the mathematical processing stage while solving problems. Using equations to compute a numerical answer is a skill to be developed in students while teaching problem solving procedure in physics classroom (Giancoli, 2008; Reif, 2008).

Out of the numerous mathematical processes involved in physics problem solving, the present study concentrated on a few skills required to solve equations related to the problems discussed in the classroom. They are discussed below as the skills involved in the component skills of implementing problem-solving procedure. They are:

i. Computing numerical values involving powers of tens
ii. Solving algebraic equations
iii. Rearranging equations to yield a particular variable
iv. Use of trigonometric relations

Table 15 shows the distributions of items from different content areas corresponding to these skills.

Table 15

Content wise Distribution of Items in the Sub Test 'Test on the Ability to Implement Problem Solving Procedure'

Content	Implementing Problem Solving Procedure				Total
	Computing Numerical Values	Rearranging Equations	Use of Trigonometry	Solving Algebraic Equations	
Motion in a straight line.	1	0	0	0	1
Motion in a plane	0	1	1	0	2
Newton's laws of motion	0	0	1	1	2
Total	1	1	2	1	5

Table 15 shows that there are items in the sub test to assess the proficiency of students in all the above-mentioned skills related to implementing a problem solving procedure.

4) Test on the Ability to Evaluate Solution to a Problem

According to science education literature, there are two phases of problem solving: (a) initial qualitative analysis of the problem situation to determine the relevant mathematical equations and (b) interpretation of the final mathematical answer, to check for physical meaning and plausibility (Heller, Keith & Anderson, 1992; Redish & Smith, 2008; Reif, 2008).

This test concentrate on the second phase, ie., interpretation of the result or checking the physical plausibility of the solution obtained. Usually, when a solution is obtained for a problem, students rarely check whether the solution obtained is reasonable and consistent with existing theories. They are more prone to make mistakes either in the initial stage of making assumptions or in mathematical computing.

Use of calculators for computations has increased the possibilities of making illogical solutions. To quote an example, if the students are asked to find the mean of three measurements say, 24.5, 24.6 and 24.2, many students using calculators may come out with a mean of 57.17 instead of 24.43. This is because they concentrate only on the procedure, ie., to find mean add the three measures and divide by three. If this is done as a single step in the calculator, the calculator divides the last measure by three and then adds the other two measures to it, resulting in an erroneous output (here 57.17). At least few students do not reason that the mean should be close to the measures concerned, and hence nearly 24. Such computational errors affect the final solution of the problem.

In numerous situations, the students blindly follow the procedure without making certain logical assumptions in between. For example, if they come across a situation where two photons are travelling in opposite directions with velocity 3×10^8 m/s, they make the relative velocity of one photon with respect to the other as 6×10^8 m/s. Here they neglect or oversee the basic assumption in physics that nothing can have velocity greater than 3×10^8 m/s.ie., the velocity of light in vacuum.

Since it is difficult to objectively assess how often students make computational errors, all the five items in the sub test ‘Test on the Ability to Evaluate Solution to a Problem’ assess whether the students make reasonable explanations for solutions and solving procedures in problems.

The four sub tests discussed above constitute ‘The Test on Component Skills in Problem Solving’. The test is appended as Appendix C1.

These component skills in problem solving are in no way exhaustive. These skills merely indicate what might be relevant in relation to the instructional strategy developed and tested in this study.

Design and Devleopment of Strategies to Develop Skills in Problem Solving

A detailed review of related literature was conducted bearing in mind, two questions. 1) What are the component skills that lead to problem solving and 2) Which strategies enhance these component skills and total problem solving ability of students. Literature on problem solving ability provided a theoretical basis for present study. Review of literature helped the investigator to list out the various component skills in problem solving. These component skills are representing the problem, planning for solution, implementing the plan and evaluating the solution (Abdullah, 2006; Giancoli, 2008; Kuo, 2004; Mateycik, 2009; Redish & Smith, 2008; Reif, 2008). These components and their total effect on problem solving constitute dependent variable of the study.

Development of Strategies to Inculcate Problem solving Skills:

Review of diverse strategies and techniques practised by teachers and proposed by other educationists helped to inculcate the identified component skills in students. The investigator also pooled in other techniques that proved to improve problem solving skills like concept mapping (Friege & Lind, 2006; Mateycik ,2009), use of Metacognitive strategies (Abdullah, 2006; Kuo, 2004; Mestre, 2002; Pacey, 1999; Roll et al., 2006; Rowe, 1987; Teong, 2003; Vansickle & Hoge, 1991; Veenman & Spaans, 2005; Waks 2001) and peer interaction strategy (Chi, Roy, & Hausmann, 2008; Leont'ev, 1932; Luria, 1932, 1928,; Vygotsky, 1978). Systematic organisation and integration of these techniques resulted in a new instructional strategy to inculcate metacognitive abilities that the study proposes to enhance problem solving. This newly developed strategy was named 'Metacognitive Strategy Instruction'. The strategy instructed to a group of students working independently is Experimental Treatment 1. This group of students is called Metacognitive Strategy (MS) Group.

The strategy instructed to a group of students, who were divided into small heterogeneous groups of four or five to facilitate peer interaction is Experimental Treatment 2. This group of students is called Peer Interacting Metacognitive Strategy (PIMS) Group.

The method of instruction usually followed by higher secondary physics teachers is the control treatment. The group of students subjected to control treatment is called Conventional Strategy (CS) Group.

Metacognitive Instructional Strategy is a four phased instructional strategy. The first three phases are common to all the three groups including control group. The experimental groups differ by the presence of a fourth phase, that is, the Metacognitive phase. The phases in each of three treatments are detailed below.

Phase 1: Presentation of Knowledge domain.

This phase is common to all the groups. In this phase the teacher presents the concepts and the relation between them as an interconnected fabric in the form of a concept map. The concept map is developed on the black board as the teacher explains each concept (e.g., Two Dimensional Motion) and the sub concepts (e.g., Circular Motion) with examples from real life situations. The teacher introduces the minor concepts(e.g., Centripetal Acceleration) related to each sub concept and explains how they can be computed from various physical quantities(e.g., linear velocity). Meanwhile, teacher also demonstrates how each of the equations can be used to solve problems.

For example Concept map on ‘Motion in a Plane’, developed in the class and presented to the students are shown in Figure 3.

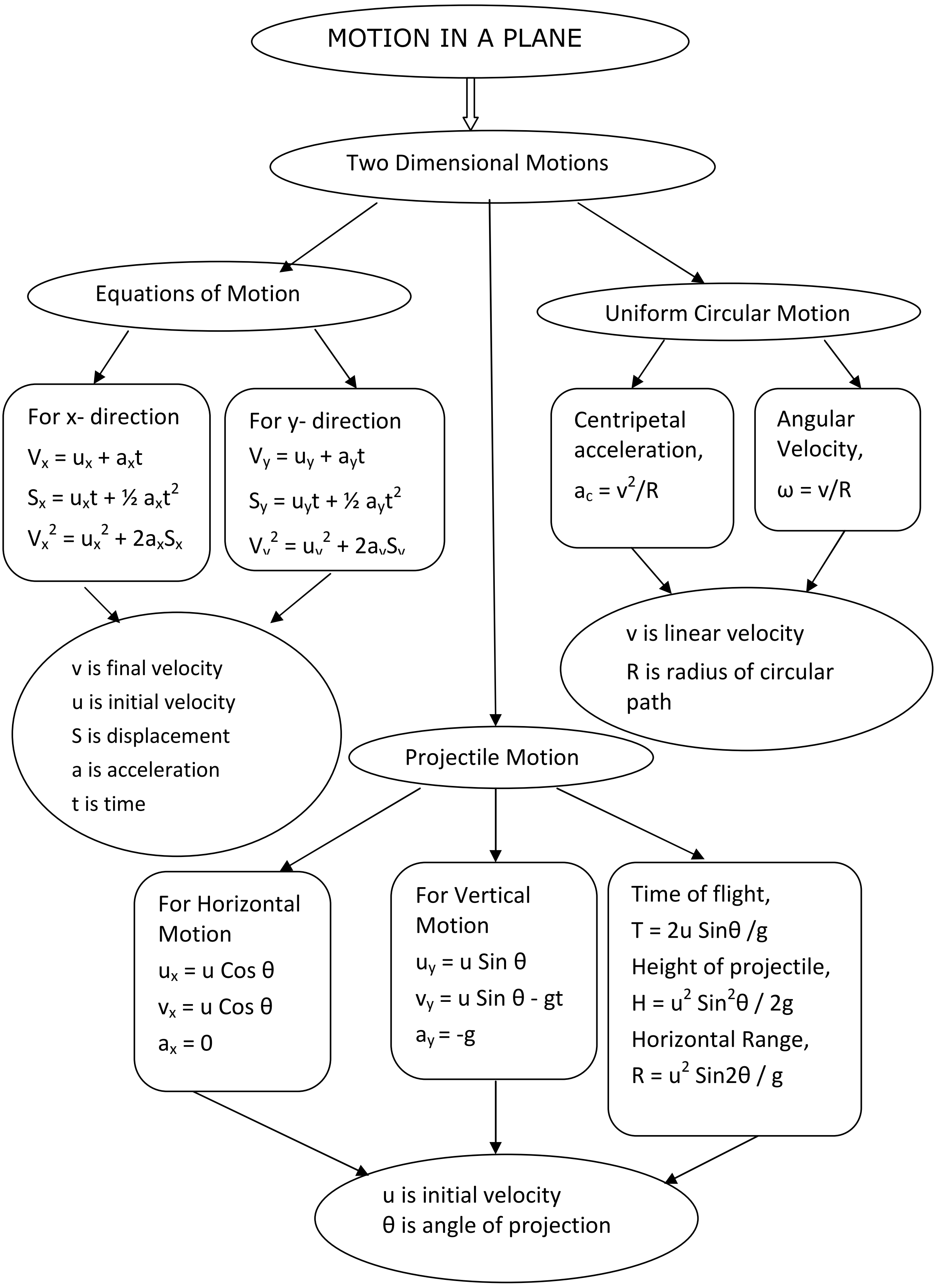


Figure 3: An Illustrative Concept Map on 'Motion in a Plane'

Phase 2: Presentation of the Problem

Like the first phase, this phase also is common to all the three groups. In this phase teacher presents a story problem where numerical values are embedded in a real life situation involving the physics concepts under discussion. Students have to estimate the unknown quantities using the concepts and relationships presented to them in the previous phase.

For example after development of the concept map illustrated (Figure 3) during Phase 1, the following problem was given in phase 2.

> A boy standing in a stationary open lift throws a ball upwards with the maximum initial speed he can, equal to 49 m/s. How much time does the ball take to return to his hands?

Phase 3: Problem solving procedure

This phase consists of four steps in which a given problem is solved. This phase is also common to all the three groups. The four steps are detailed below along with the procedure for working out the problems are illustrated using the problem given as an example in the previous phase.

<u>Step 1: Surface representation</u>

In this step, the problem situation is represented in the form of a diagram. All the given variables with their values and the unknown quantities to be determined are indicated in the diagram.

For example, for the problem in the previous phase, the diagram would look like Figure 4.

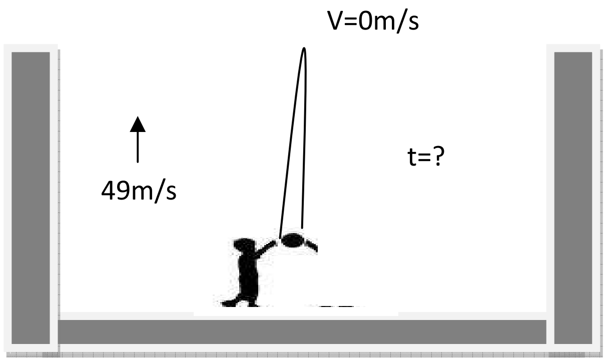


Figure 4: Surface Representation of a Problem: An Illustration

Step 2: Structure Representation

In this step teacher and students discuss the physics concepts in the problem situation. They view the problem in the frame work of physical science principles and make the assumptions necessary for the solution of the problem.

For example, in the problem considered here the discussion can be as follows.

Teacher : *Let us take the case of a ball moving upwards. When the ball moves upwards, what happens to its velocity?, Does it increase or decrease?*

Pupil : *Decrease*

Teacher : *So, Is its acceleration positive or negative?*

Pupil : *Negative*

Teacher : *What will be the magnitude of acceleration?*

Pupil : *9.8*

Teacher : *Why is it 9.8?*

Pupil : *The ball is accelerated by gravity*

Teacher : *So we can take the acceleration,a= - 9.8 m/s²*

At the topmost point the ball remains stationary for a moment and comes back. So what will be the final velocity for upward motion?

Pupil : *zero*

Teacher : *Yes, so we can take final velocity, v = 0m/s*

Step 3: Planning the solution

In this step, on the bases of the previous representations of the problem, teacher and pupils together decide which equations can be used to solve the problem. They also plan how to work out the problem using the equations and assumptions, through a series of steps.

For example in planning the solution of the throwing problem illustrated above was done as follows,

Teacher : *We have initial velocity, u*

Final velocity, v

And acceleration, a

The problem is to find time, t.

So which equation can we use to solve this problem?

Pupil : *$v = u + at$*

Teacher : *This will give us only the time taken for upward motion. But the time taken for upward motion will be same as the time taken for downward motion. Can you guess how to find the total time taken by the ball to return to the boy's hand?*

Pupil : *We will just have to take twice the time for upward motion.*

Teacher : *Yes. Good.*

<u>Step 4: Implementing the plan</u>

In this step teacher and students proceed according to their plan and solve the problem.

While implementing the plan, the above illustrated problem of throwing the ball, was solved as follows.

Teacher : *Now we can proceed according to our plan.*

(Teacher work out on the black board)

Substituting the values in equation, $v = u + at$,

$0 = 49 – 9.8 \times t$

$9.8 \times t = 49$

$t = 49/9.8 = 5$ *seconds.*

This is the time for upward motion, so the total time taken by the ball to fall back to the boys hand is twice this time.

2×5 = 10 seconds.

Phase 4: Metacognitive Analysis

In usual classroom teaching, teachers do not further reflect upon the problem and its solution, once a problem is solved. So this phase is not a part of the Control Treatment. This is not instructed to the CS group.

This phase is a part of both Experimental Treatment 1 and Experimental Treatment 2. For MS group, subject to Experimental Treatment 1, this phase continued without any change in the class room structure. But for PIMS group, subject to Experimental Treatment 2, students were asked to sit in separate heterogeneous groups of five or four and discuss in each step. Thus in PIMS group this phase was carried out in a frame work of peer interaction.

This phase consisted of three steps. The different steps are detailed below and their working procedures are illustrated using the ball throwing problem solved in the previous phase.

Step 1: Error Analysis

In this step students investigate whether the equations used are consistent unit wise, whether the assumptions made are correct and whether the solution obtained is reasonable?

During error analysis of the ball throwing problem the class preceded as follows.

Teacher : *The equation we used is, v= u+ at*

Write the units used for each of the quantities and see whether they are the same for each term on either side of the equation.

Pupil : *(work out in their books)*

$v = u + at$

$m/s = m/s + m/s^2 \times s$

$m/s = m/s + m/s$

The units for all the terms are the same.

Teacher : *Therefore the equation is consistent unit wise.*

We assumed that time for upward motion is equal to time for down ward motion. For further confirmation, let us calculate separately calculate time for downward motion by taking values,

$u = 0\ m/s,\ a = 9.8\ m/s^2,\ v = 49 m/s$

Pupil : *(Workout in their books)*

$v = u + at$

$49 = 0 + 9.8 \times t$

$t = 49/9.8 = 5s.$

Teacher : *This is same as the time for upward motion. So our assumption is correct.*

Step 2: Monitoring the Procedure

In this step teacher makes the students reflect on the procedure followed so that the physical science principles and the strategy for solving the problem gets fixed in their mind. Teacher does that by asking a set of reflective questions like those given in Table 16.

Table 16

Reflective Questions Posed to Studnets while Monitoring Problem Solving Procedure and their Purpose

Illustrative Reflexive Questions	**Purpose Served by the Questions**
Q1: What was your first step while solving the problem?	This helped the students to recollect and realise the need to represent the problem diagrammatically.
Q2: Which physical quantities were given directly?	This helped the students to reflect on the way they drew out the known quantities from the problem.
Q3: Which physical quantities were to be determined?	This helped the students to summon up the way they identified the unknown physical quantities.
Q4: How did you obtain the required relations?	This set the systematic way of planning to solve the problem in the mind of the students.
Q5: What assumptions did you make?	This threw light upon various physical science principles that govern nature and facilitated further logical assumptions in future problem solving.
Q6: How did you solve the problem?	This reflected on the methods of implementing solution plans to physics problems.
Q7: Did you face any difficulty in any stage?	This helped both the teacher and students to identify the short coming in planning solution to problems and implementing the plans.
Q8: How did you overcome the difficulties?	This helped in the onset of an open discussion on strategies and sharing of ideas among the students.

Step 3. Analogical Problem Solving

In this step teacher provided a problem similar to the one presented in phase 2 and asked students to solve it, following all the steps in phases 3 and 4. Students in MS group, subjected to Experimental treatment 1 did that independently, while students in PIMS group, subjected to Experimental Treatment 2 did that in small groups, interacting with their peers.

Example: A problem analogical to the one presented in phase 2 example is as follows.

Analogical Problem: A person standing in an open lift moving with uniform velocity throws a ball upwards with an initial speed of 40m/s. How much time does the ball take to return to his hands?

The four phased Metacognitive Strategy Instruction is summarized in Table 17.

Table 17

Summary of Various Phases of the Metacognitive Strategy Instruction for Problem Solving used in this study

Phases	Description
Phase 1: Presentation of Knowledge domain.	• Teacher presents the concepts and the relation between them as a concept map. • The concept map is developed on the black board • Teacher explains each concept and the sub concepts with examples from real life situations. • Teacher explains how minor concepts can be determined from various physical quantities. • Teacher demonstrates how the presented equations can be used to solve problems.
Phase 2: Presentation of the Problem	• Teacher presents a story problem • In the problem numerical values are embedded in a real life situation. • Students estimate the unknown quantities using the concepts and relationships presented to them in the previous phase.
Phase 3: Problem solving procedure.	Consists of four steps • Step 1: Surface representation The problem situation is represented in the form of a diagram. • Step 2: Structure Representation Teacher and students discuss the physics concepts in the problem situation and make the assumptions necessary for the solution of the problem. • Step 3: Planning the solution Teacher and pupils together decide which equations can be used to solve the problem and plan how to work out the problem. • Step 4: Implementing the plan Teacher and students proceed according to their plan and solve the problem.
Phase 4: Metacognitive Analysis	Consists of three steps • Step 1: Error Analysis Students investigate the equations used, the assumptions made and solution obtained. • Step 2: Monitoring the Procedure The students reflect on the procedure followed • Step 3. Analogical Problem Solving Students solve an analogical problem following all the steps in phases 3 and 4.

Based on this four phased strategy named, Metacognitive Strategy Instruction 30 lessons were prepared and implemented. Out of the thirty lessons six lessons consists only of the first phase – Presentation of the knowledge Domain. Out of these six lessons, two lessons each were used to present knowledge domain pertaining to the three units namely, Motion in a Straight Line, Motion in a Plane, Laws of Motion. Each of these sets of two lessons was followed by eight lessons where students solved related problems going through the rest of the phases. Thus there were 24 lessons on solving problems, each lesson comprising of a presentation problem and an analogical problem.

The problems presented along with their analogical problems for students to workout in each unit are listed below.

Table 18

Illustrative Problems and Their Corresponding Analogical Problems Used in the Lessons in the Unit 'Motion in a Straight Line'

Illustrating Problems	Analogical Problems
1. The engine of an electric train passes a stationary car with a velocity of 6 m/s. It takes 10 seconds to the tail end of the train to pass the same car by which time its velocity is 9m/s. Calculate the acceleration of the train.	1. A car enters a tunnel with a speed of 4 m/s. It takes 55 seconds for the car to come out of the tunnel by which time its velocity is 6 m/s. Calculate the acceleration of the car.
2. An electron travelling with a speed of 5×10^3 m/s passes through an electric field with an acceleration of 10^{12} m/s^2. How long will it take the electron to double its speed?	2. A proton travelling with a speed of 3×10^2 m/s passes through an electric field with an acceleration of 10^6 m/s^2. How long will it take the proton to attain thrice its original speed?
3. A motor car moving with a uniform velocity of 20m/s comes to stop on the application of breaks, after travelling a distance of 10m. What is its acceleration?	3. A train reaches the station with a velocity of 60 m/s. It travels 20m before coming to a halt. What is its acceleration?
4. A train 100 meter long is moving with a speed of 60 km/h. In what time shall it cross a bridge 1 km long?	4. Feroke railway station is 1.5 km long. How long will it take a 150 m long train to pass the station without stopping, if it is travelling with a constant speed of 70 km/h?
5. A man travels in his car from home to office at 40 m/s and from office to home at 60 m/s. Calculate average speed and average velocity of that person.	5. A person drives to the fish market at a speed of 50 km/h and returns home at a speed of 70 km/h. What is the average speed and average velocity of the person?
6. On a horizontally moving belt, a child runs with a speed of 8km/h towards his mother on the ground 500m away. The belt is moving towards the mother with a speed of 4km/h. In what time will the child reach his mother?	6. A train moves towards a tree, 3 km away with a speed of 100km/h. A monkey runs on the train in the same direction with a speed of 10km/h. In what time will the monkey reach the tree?
7. A train moves towards north with a speed of100km/h. A monkey runs on the train towards south with a speed of 8km/h. What is the relative velocity of the monkey with respect to an observer on the platform?	7. A train moves towards south with a speed of 80km/h. A kangaroo jumps on the train with a speed of 12 km/h towards north. What will be the velocity of the kangaroo with respect of an observer on ground?
8. A car moving along a straight road with a speed of 72km/h stops with in a distance of 200m. How long does it take the car to stop?	8. An aeroplane lands with a horizontal velocity of 144km/h and comes to stop with in a distance 400m on ground. How long does it take the aeroplane to stop?

Table 19

Illustrative Problems and Their Corresponding Analogical Problems Used in the Lessons in the Unit 'Motion in a Plane'

Illustrating Problem	**Analogical Problem**
1. A projectile is fired with a horizontal velocity of 330m/s from the top of a cliff 80m high. How long will it take the projectile to strike the level ground at the base of the cliff?	1. An aircraft 500m above ground is flying with a horizontal velocity 15m/s. It drops a bomb. How long will it take the bomb to reach the ground?
2. A boy can throw up a ball to a maximum height of 10m. To what distance can he throw the same ball on the ground?	2. A kangaroo can jump to a maximum height of 5m. To what maximum distance can it jump on ground?
3. A boy revolves a stone on a string 10cm long steadily, completing 10 revolutions in 10 seconds. What is the angular speed of the stone?	3. An insect trapped in a circular groove of radius 12cm moves along the groove steadily and completes 7 revolutions in 100s. What is the angular speed of the insect?
4. A helicopter 500m high is flying horizontally with a speed of 144km/h. It drops a food packet. How far should a boy just below the helicopter run to get the food packet?	4. An aeroplane is flying in a horizontal direction with a velocity of 360km/h at a height of 1960m. How far from a given target, should it release a bomb to hit the target?
5. A monkey jumps from the branch of a tree 20m high from the ground with a horizontal velocity of 40m/s. How long will it stay in air?	5. A bird flying at a height of 60m with a horizontal speed of 50m/s drops a fish in its mouth. How long will it take the fish to reach the ground?
6. A boy is playing with a ball in a train moving with a speed of 100km/h. If he throws up the ball with a speed of 10m/s. How long will the ball stay in air before reaching his hands?	6. A basket ball player throws up the ball with a speed of 20 m/s as he runs with a speed of 30m/s. In what time will the ball reach back to his hands?
7. A ball is projected with a velocity of 10m/s at an angle of 60^0 with the horizontal. What is its velocity at the highest point?	7. A stone is thrown with a velocity of 15m/s at an angle of 30^0 with the horizontal. What are its horizontal and vertical components of velocity at its highest point?
8. The ceiling of a roof is 25m high. What is the maximum distance that a ball thrown at a speed 40m/s can go without hitting the roof?	8. A boy kicks a football with a speed of 50m/s. If it reaches a height of 15 m from the ground, what will be the distance covered by the ball as it touches the ground?

Table 20

Illustrative Problems and Their Corresponding Analogical Problems Used in the Lessons in the Unit 'Newton's Laws of Motion'

Illustrating Problem	Analogical Problem
1. A ship of mass 3×10^7 kg initially at rest is pulled by a force of 6×10^4N. Calculate the acceleration attained by the ship.	1. A body of mass 12kg is moving with an acceleration of 50m/s^2. Calculate the force acting on it.
2. A person weighting 75kg stands in an elevator. What will be the apparent weight of the man when the elevator moves up with an acceleration of 10m/s^2?	2. A monkey of mass 40kg climbs up a rope that can withstand a maximum tension of 600N. What will happen to the rope if the monkey climbs up with an acceleration of 6m/s^2?
3. A hunter has a machine gun that can fire 50g bullets with a velocity of 800m/s. A 40kg tiger springs at him with a velocity of 10m/s. How many bullets must the hunter fire into the tiger in order to stop it in its track? (Neglect pain).	3. A stone weighing 50kg is rolling towards a person with a speed of 8m/s. If the person has a machine gun that can fire 50g bullets with a speed of 1000m/s, how many bullets can stop the stone?
4. A body placed on a rough inclined plane just begin to slide when slope of the plane is 1 in 4. Calculate coefficient of friction.	4. A body placed on a rough inclined plane just begins to slide when the angle of inclination becomes 30^0. Calculate the coefficient of friction of the inclined plane.
5. A force of 20N is applied on a hockey ball at an angle 30^0 with the X-axis. What is the vertical component of force?	5. A cricketer throws a ball with a force of 15N making an angle of 40^0 with the horizontal. What is the horizontal component of force?
6. A horizontal force of 1.2 kgf is applied to a 1.5kg block, which rest on a horizontal surface. If co-efficient of friction is 0.3. Find acceleration produced.	6. A 2kg wooden block is resting on a surface of co-efficient of friction 0.35. How much acceleration will the wooden block have if a force of 2.8kgf is applied on it?
7. A force of 60N is applied on a stone (which was initially at rest) of mass 3 kg for ½ minute. Find the velocity gained by the stone.	7. A stone of mass 2kg is initially at rest. What force if applied for 20 seconds will make it move with a speed of 600m/s?
8. Two masses 8kg and 12kg are connected at the two ends of a light inextensible string that goes over a frictionless pulley. Find the acceleration of the masses, and the tension in the string when the masses are released.	8. A string can withstand a maximum tension of 100N. Two masses 10kg and 8kg are connected at its ends and the string goes over a frictionless pulley. Will the string break when the masses are released?

The detailed lesson transcripts are appended ad Appendix D.

Sample for Study

Higher Secondary School Studnets of Kerala comprise the population of the study. Out of the fourteen districts in Kerala, Kozhikode district was randomly selected for the study. Three Higher Secondary Schools with students of comparable socio-economic status and educational background were choosen from Kozhikode district. These were Farook Higher Secondary School, Farook College; Government Ganapath Vocational Higher Secondary School, Feroke; and Government Vocational Higher Secondary School, Cheruvannur.

Sample used for standardization of tools

Out of three schools, two schools namely Farook Higher Secondary School and Government Ganapath Vocational Higher Secondary School were randomly assigned for providing sample for standardization of tools. Each of these schools had four grade 11 classes. There were around 50 students in each of these eight classrooms. From among the eight classes, three classes were randomly selected as standardization sample. In these three classes two (out of four) were from Government Ganapath Vocational Higher Secondary School and one class was (out of four) from Farook Higher Secondary School. In these three classes same tests were employed. Out of around 150 students who were administered the test, 112 students gave data which was complete in all respects. Therefore these 112 students were used as sample for standardization of tests.

Sample used in experiment

For conducting experiment, Government Vocational Higher Secondary School, Cheruvannur was randomly choosen. There were three grade 11 classes with around 50 students in each class. Pre-test (Previous Problem Solving Ability) were conducted in all the three classes. After matching the three groups on Previous Problem Solving Ability, 38 students each from the three classes were choosen for the intervention. The three groups of 38 studnets each were then randomly assigned into two experimental (PIMS and MS) and control (CS) group. Sampling procedure is illustrated in Figure 5.

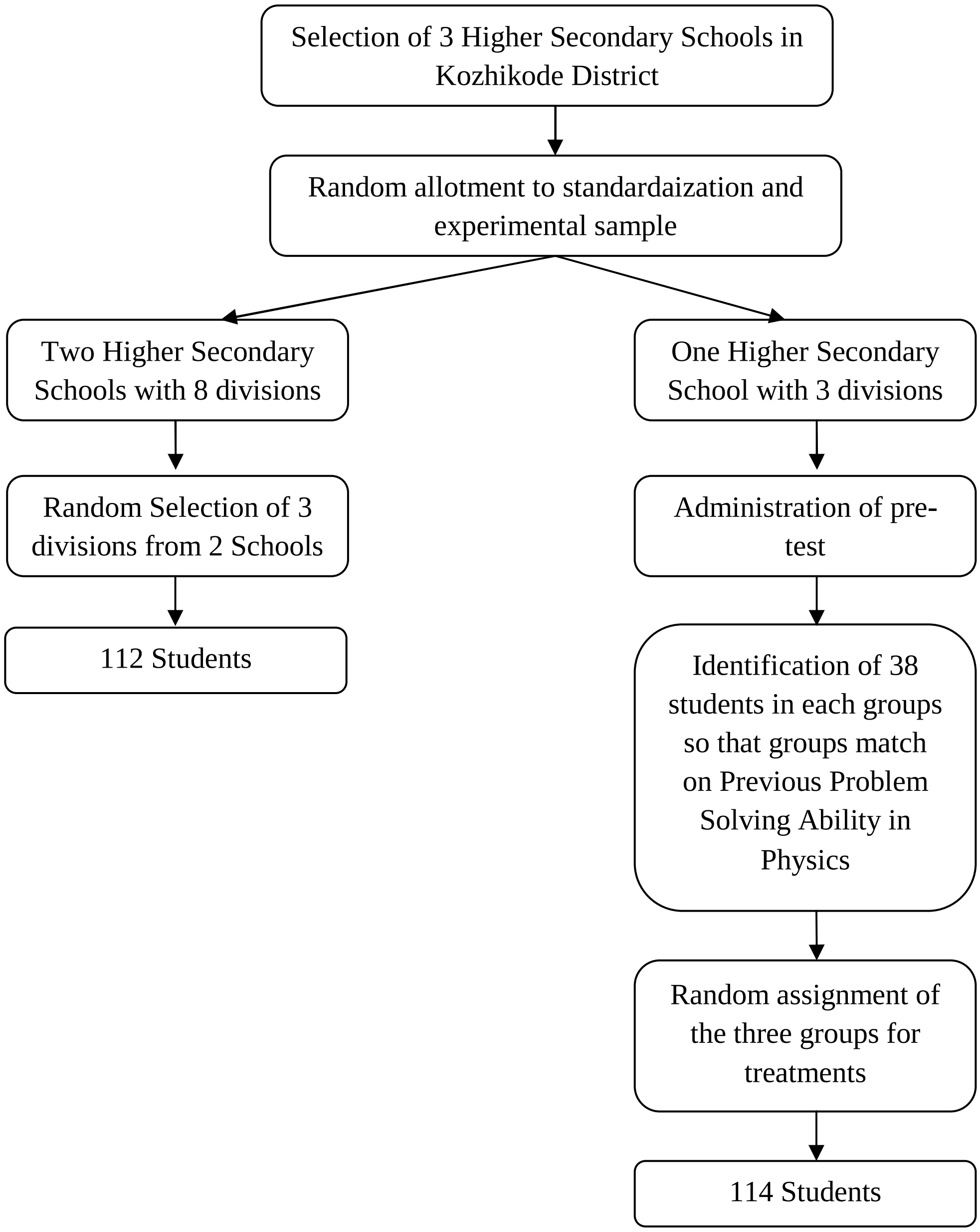


Figure 5 : Sampling Procerdure

Relevance of matching the groups on previous problem solving ability

Many authors have demonstrated in numerous factors effecting problem solving skills. These include fluid intelligence and crystallized intelligence (Horn, & Cattell, 1966), memory and meta-memory (Kreutzer, Leonard, Flavell, & Hagen, 1975), reflection impulsivity (Borkowski, Peck, Reid, & Kurtz, 1983). Schoenfeld (1985) argued that four factors are necessary and sufficient for understanding the quality and success of problem solving, viz., (1) the knowledge base, (2) Problem solving strategies, (3) Control: monitoring and self regulation, or metacognition and (4) Beliefs and the practices that give rise to them.

More recent literature review did not result in a much different taxonomy on the factors influencing problem solving performance, as can be concluded from the broad taxonomy of problem solving attributes put forward by Carlson & Bloom (2005). The dimensions of the taxonomy are (1) Resources, ie., the conceptual understandings, knowledge, facts and procedures. (2) Control, ie., the selection and implementation of resources involving, planning, monitoring, decision making, conscious metacognitive acts etc... (3) Methods, ie., the general strategies used while working a problem, like constructing new ideas, carrying out computations etc... (4) Heuristics, ie., more specific procedures and approaches used when working a problem, like observing symmetries, altering the given problem so that it is easier etc... 950 Affect ie., attitudes (enjoyment, motivation, interest), beliefs (self confidence, pride, persistence, etc...), emotions (joy, frustration, impatience, etc...) and values/ ethics (mathematical intimacy and integrity).

Since all these factors and processes effects the previous problem solving skills of students, the investigator, instead of assessing each of these factors independently, made the study concise by assessing previous problem solving ability in physics (in the area of mechanics) and matched the two experimental and control groups based on its measures.

Match among the Experimental and Control groups:

Based on the scores of pre-test, the three groups were matched following the procedure detailed below.

Step 1: Pre – test was conducted among the three intact classes A, B and C.

Step 2: The students in each class were ranked according to the scores obtained for pre-test.

Step 3: The students in the three classes were selected in the order of their pre-test scores for inclusion in as many groups, such that the groups were matched on the mean of pre-test scores. (One to one matching was not strictly followed as only 28 students out of 40 could be obtained as sample in each group if attempted). There were 38 students in each of the three groups.

Step 4: Correlation between ranked scores of pairs of the selected groups (n=38) were determined. The following values of Pearson's correlation coefficient were obtained.

Table 21

Correlation Coefficients between Pre-test Scores of the Three Groups of Students

	Group A	Group B	Group C
Group A	--	--	--
Group B	0.96	--	--
Group C	0.98	0.96	--

The high values for correlation coefficient shows that the groups are matched on their pre-test scores on problem solving ability.

Step 5: The matched groups were then randomly assigned in to PIMS (Peer Interacting Metacognitive Strategy Group), MS (Metacognitive Strategy Group) and Control group

Step 6: To demonstrate the match between the groups further, the pre-test scores for each group subjected to ANOVA.

Table 22

Results of ANOVA of Previous Problem Solving Ability of PIMS, MS and CS groups

Equating Variable	Source of Variance	SS	df	MS	F
Previous Problem Solving Ability	Between Groups	.123	2	.061	
	Within Groups	340.658	111	3.069	.020
	Total	340.781	113		

Table 22 shows Previous Problem Solving Ability does not differ significantly among PIMS (*M*=3.58, *SD*=1.84), MS (*M*=3.63, *SD*=1.68) and Control (*M*=3.66, *SD*=1.73) groups, F (2,111) = 0.020, $p > 0.05$

Results of one-way ANOVA of Previous Problem Solving Ability revealed that students of PIMS, MS and CS groups are having same level of Problem Solving Ability before intervention and any difference in their Problem Solving Ability can be attributed to the intervention namely Peer Interacting Metacognitive Strategy Instruction (Experimental Treatment I), Metacognitive Strategy Instruction (Experimental Treatment II) or Conventional Instructional Strategy (Controll Treatment).

Experimental interventions were carried out in PIMS and MS groups. Controlled interventions were carried out in control group. After the interventions post-test and general test on problem solving in other areas of physics were administered in all the three groups. Diagnostic test was conducted in PIMS and MS group.

Statistical Analyses Used in the Study

The present study employed the following statistical techniques to realize the objectives set for the investigation. The statistical analysis were carried out with statistical package for social sciences (SPSS).

Tests of Normality

Normal distribution is an underlying assumption of many statistical procedures such as t-test, regression analysis and Analysis of Variance (ANOVA). When the normality assumption is violated, interpretations and inferences may not be reliable or valid. The present study employs three common procedures namely, graphical method (histograms, Box-plots, and Q-Q plots), numerical methods (Skewness and Kurtosis) and formal normality test (Shapiro-Wilk test).

Shapiro-Wilk test is most suitable for small sample size (Shapiro & Wilk, 1965). It is able to detect departures from normality due to either Skewness or Kurtosis, or both (Althouse, Ware, & Ferron, 1998). It is a preferred test because of its good power properties (Mendes & Pala, 2003). The value of Shapiro-Wilk test statistic (S-W) lies between zero and one. Small values of S-W leads to the rejection of normality where as a value of one indicates normality of the data.

Test for Homogeneity

Levene's test is an inferential statistic used to assess the equality (homogeneity) of variances for a variable calculated for two or more groups. Statistical procedures like ANOVA and Test of Significance of Differences between Means assumes that variances of the populations from which different samples are drawn are equal. Levene's test assesses this assumption. If the resulting F-value of Levene's test is less than some significance level (typically .05), the obtained differences in sample variances are unlikely to have occurred based on random sampling from a population with equal variances (Levene, 1960).

Therefore the F-value of Levene's test should have a significance level greater than .05, for the differences between means to be homogeneous. Even if the variances between means are not homogeneous, instead of Fisher's F, Welch F can be computed for making inferences (Leech, Barrett, & Morgan, 2005).

Correlation Analysis

The present study was conducted with three intact classroom groups for practical reasons. Therefore in order to match the groups before the treatment, a variable namely previous problem solving ability in physics (pre-test) was introduced. The students were then ranked according to the scores and their correlation was computed.

Correlation is the relationship between two or more paired variables or two or more sets of data. The degree of relationship is measured and represented by the coefficient of correlation. The most often used and most precise coefficient of correlation is the Pearson Product Moment Correlation denoted by the symbol 'r'. Pearson Product Moment Correlation was used to find out the degree of relationship between the problem solving ability in physics and the use of Metacognitive strategies during problem solving.

Verbal Interpretation of 'r' was done according to the method provided by Garrett (1937). The coefficient of correlation between two variables is described as 'high', 'marked' or 'substantial', 'low' or 'negligible' depending upon the numerical index of 'r'.

The interpretation is as shown below.

i. 'r' from 0.00 to ±0.20 – denotes indifferent or negligible relationship.
ii. 'r' from ±0.20 to ±0.40 – denotes low or slight relationship.
iii. 'r' from ±0.40 to ±0.70 – denotes substantial or marked relationship.
iv. 'r' from ±0.70 to ±1.00 – denotes high to very high relationship.

One-way ANOVA

One-way Analysis of Variance was used to compare each of the following variables.

- Previous Problem Solving Ability
- Analogical Problem Solving Ability

- Problem Solving Skills in Physics
- Use of Metacognitive Strategies in Problem Solving

These variables were compared between each of the two Experimental Groups (PIMS and MS groups) and the Control Group (CS group).

In this case the critical ratio is

$F = MSS_B/MSS_W$

$= (SS_B/df_B) / (SS_W/df_W)$

(Best & Kahn, 2006)

Where,

MSS_B – Mean sum of squares between groups

MSS_W – Mean sum of squares within groups

SS_B – Sum of squares between groups

SS_W – Sum of squares within groups

df_B = n-1, degrees of freedom between

df_W = N-n, degrees of freedom within

The significance of an F ratio was assessed with reference to the Table of F with (n-1, N-n) degrees of freedom for either .05 or .01 level of significance.

If, for a required level of significance the value obtained for F is higher than the table value of F, then the difference between group means was said to be significant for the level of significance of the test.

As the F value was significant in the case of each of the variables,

- Analogical Problem Solving Ability
- Problem Solving Skills in Physics

- Use of Metacognitive Strategies in Problem Solving

between each of the two Experimental groups (PIMS and MS groups) and the Control group (CS group), the test of significance of means was used to find out where the difference lies among the groups.

Test of Significance of Difference between Means for Small Independent Samples

Test of significance of difference between means was used to compare the dependent variables namely, Analogical Problem Solving Ability in Physics (post-test), General Problem Solving Skills in Physics and Component Skills in Problem Solving between the two Experimental and Control groups.

Effect Size

Recent studies with testing of statistical significance provide information about effect size along with statistical significance (American Psychological Association, 2001; Kline, 2004; Wilkinson and the Task Force on Statistical Inference, APA Board of Scientific Affairs, 1999). Effect size is seen as much more essential than significance, and many international journals have insisted that statistical significance be escorted by indications of effect size (Capraro & Capraro, 2002; Olejnik & Algina,2000; Thompson, 2002).

An effect size is simply a way of quantifying the difference between two groups (Coe, 2000). In the present study it informs

- How much is the effect of Peer Interacting Metacognitive Strategy Instruction on Analogical Problem Solving Ability and Problem

Solving Skills in Physics compared to the Conventional Instructional Strategy and

- How much is the effect of Metacognitive Strategy Instruction on Analogical Problem Solving Ability and Problem Solving Skills in Physics compared to the Conventional Instructional Strategy
- How much is the effect of Peer Interacting Metacognitive Strategy Instruction on Analogical Problem Solving Ability, Problem Solving Skills in Physics and Use of Metacognitive Strategies in Problem Solving Compared to the Metacognitive strategy Instruction

There are several different calculations of effect size (Capiro & Capiro, 2002; Richardson, 1996): r^2, adjusted R^2, η^2, ω^2, Carmer's V, Kendall's W, Cohen's d, and Eta. Different kinds of statistical treatments use different effect size calculations.

In the present study, the effect size is determined and interpreted yielding the statistics Cohen's d, η^2 and ω^2. Cohen's d is determined using the formula given by Glass, McGraw and Smith (1981).

$$\text{Cohen's d} = \frac{\text{mean of experimental group} - \text{mean of control group}}{\text{standard deviation of control group}}$$

Standard deviation of the control group is preferable as the denominator as it provides the best estimate of standard deviation, since it consists of a representative group of the population who have not been effected by the experimental intervention (Coe, 2000).

Cohen's d can be interpreted as follows (Coe, 2000):

0 – 0.20 = weak effect

0.21 – 0.50 = modest effect

0.51 – 1.00 = moderate effect

> 1.00 = strong effect.

The effect size index, η^2 was worked out using SPSS. In SPSS, it is given as 'partial η^2'. The value of partial η^2 can be interpreted as follows.

0.01 = a very small effect

0.06 = a moderate effect

0.14= a very large effect (Cohen, 1988).

Further it can be inferred that 'partial η^2' ×100 percent of the variance in the Dependent Variable can be accorded to the Independent Variable.

Another less biased effect size measure that gives a more accurate representation of the relationship between the Independent Variable and Dependent Variable is ω^2. It can be calculated using the equation,

$$\omega^2 = \frac{SOS_b - (k-1)MS_w}{SOS_t + MS_w}$$

Where, SOS_b – Sum of Squares between groups

MS_w – Mean Squares within groups

SOS_t – Total Sum of Squares

k – Number of groups under comparison

Moreover it can be more accurately inferred that 'ω^2' ×100 percent of the variance in the Dependent Variable can be accorded to the Independent Variable.

Multiple Regression Analysis

Multiple regression is a statistical tool that allows the examination of how multiple independent variables are related to a dependent variable. In the present study multiple regression analysis was used to examine how much did the post intervention strategies, ie., Use of Metacognitive strategies contribute to Problem Solving Skills in Physics of the two experimental groups.

Multiple correlations (R) is the correlation between the actual scores and the scores predicted by two or more independent variables. It is more suitable for determining the percentage of variance of the predicted scores that can be examined by the predictors. R^2 is the percentage of the variance of the predicted (dependent) variable that is due to, or explained by the combined predictor (independent) variables.

All statistical computations were made using SPSS software.

Chapter IV

ANALYSIS

- ***Preliminary Analysis***
  - *Indices of*
    - *Previous Problem Solving Ability*
    - *Analogical Problem Solving Ability*
    - *Problem Solving Skills in Physics*
    - *Use of Metacognitive Strategies in Problem Solving*
- ***Effectiveness of Metacognitive Strategy Instruction on Problem Solving Skills in Physics***
  - *Effect of Metacognitive Strategy Instruction on*
    - *Analogical Problem Solving Ability*
    - *Problem Solving Skills in Physics*

    of Higher Secondary School Students in Physics
  - *Effect of Peer Interaction on the Use of Metacognitive Strategies in Problem Solving of Higher Secondary School Students in Physics*
  - *Relative Efficacy of the Four Component Skills of Metacognitive Strategy on Problem Solving Skills in Physics.*

The purpose of the present study is to examine the Effect of Metacognitive Strategy Instruction on Problem Solving Skills in Physics among Higher Secondary School Students. The design used for the study was Non-equivalent Pre-test Post-test Control Group Design. The collected data was analyzed using the statistical techniques namely, Analysis of Variance, Test of Significance of Difference between Means, followed up by Effect Size and Multiple Regression Analysis.

Preliminary Analysis

To find out the important statistical indices of measures of central tendency, measures of dispersion and distribution of the variables viz., Previous Problem Solving Ability, Analogical Problem Solving Ability, Problem Solving Skills in Physics, and Use of Metacognitive Strategies in Problem Solving were calculated. Comparability of the distribution of the scores of these variables to a normal distribution was further tested in terms of Shapiro-Wilk statistic. The results of these preliminary analyses done are presented in four sub–sections, corresponding to the four variables viz., Previous Problem Solving Ability, Analogical Problem Solving Ability, Problem Solving Skills in Physics, and Use of Metacognitive Strategies in Problem Solving.

Indices of Distribution of Previous Problem Solving Ability

The important statistical indices viz., mean, median, mode, standard deviation, skewness, kurtosis of the control variable Previous Problem Solving Ability were compared for each of the two Experimental groups

(PIMS group and MS group) and the Control Group (CS group). These are presented in Table 23.

Table 23

Indices of Previous Problem Solving Ability of Higher Secondary School Students in Physics

Groups	Mean	Median	Mode	SD	Skewness	SE	Kurtosis	SE
PIMS	3.85	4	4	1.84	-.27	.38	-.35	.75
MS	3.63	4	3	1.68	-.17	.38	-.57	.75
Control	3.66	4	4	1.73	-.43	.38	-.26	.75

Table 23 reveals the following. Mean (3.84), median (4), and mode (4) of Previous Problem Solving Ability in PIMS group are nearly equal. The indices of skewness (-.27, *SE*=.38) and kurtosis (-.35, *SE*=.75) indicate slightly negatively skewed, platy kurtic distribution of Previous Problem Solving Ability in PIMS group. Likewise, mean (3.63), median (4), mode (3) of Previous Problem Solving Ability in MS are nearly equal. The skewness (-.17, *SE*=.38) and kurtosis (-.57, *SE*=.75) indicate slightly negatively skewed, platy kurtic distribution of Previous Problem Solving Ability in MS group. Similarly, mean (3.66), median (4), mode (4) of Previous Problem Solving Ability in control group are nearly equal. The skewness (-.43, *SE*=.38) and kurtosis (-.26, *SE*=.75) indicate slightly negatively skewed, platy kurtic distribution of Previous Problem Solving Ability in control group. The ratio between skewness and its standard error, and that between kurtosis and its standard error are less than 1.96 for each of the groups, PIMS, MS, and control. Therefore it can be concluded that the distribution of scores for Previous Problem Solving Ability in physics of each of the groups, PIMS, MS, and control are normal at 95percent confidence (Kim, 2013). Table 23 further shows that the mean scores for Previous Problem Solving Ability for the three groups, PIMS (M =3.58), MS (M=3.63), Control (M=3.66) are almost equal.

The nearly equal mean scores indicate the match among the three groups on problem solving ability in physics before the intervention as reported in methodology ‘Previous Problem Solving Ability does not differ significantly among PIMS (*M*=3.58, *SD*=1.84), MS (*M*=3.63, *SD*=1.68) and Control (*M*=3.66, *SD*=1.73) groups, F (2,111) = 0.020, $p > .05$.

To further assess the normality and homogeneity of variance of the distribution of scores of Previous Problem Solving Ability in physics for PIMS, MS, and control group, Shapiro-Wilk test for normality and Levene test for homogeneity was done. The results of these tests are summarized in Table 24

Table 24

Indices of Normality of Distribution (Shapiro-Wilk Statistic) and Homogeneity of Variance (Levene Statistic) of Previous Problem Solving Ability in Physics of Higher secondary School Students

Groups	Shapiro-Wilk statistic (S-W)	df	Levene statistic	df_1	df_2
PIMS	.95	38			
MS	.96	38	.11	2	111
Control	.94	38			

From Table 24, the Shapiro-Wilk statistic of normality (*S-W*=.95, *df*=38, $p>.05$) suggest that normality was a reasonable assumption for Previous Problem Solving Ability in physics of PIMS group. Similarly the

Shapiro-Wilk statistic of normality (*S-W*=.96, *df*=38, *p*>.05) suggest that normality was a reasonable assumption for Previous Problem Solving Ability in physics of MS group. The Shapiro-Wilk statistic of normality (*S-W*=.94, *df*=38, *p*>.05) suggest that normality was a reasonable assumption for Previous Problem Solving Ability in physics of control group. Also for Previous Problem solving Ability, the variances were equal for the three groups namely, PIMS, MS, and control, F (2,111) =.11, p>.05. Therefore it can be concluded that the distribution of scores of Previous Problem solving Ability in Physics for the three groups, PIMS, MS, and control group are normal, and the variances among the three groups are homogeneous.

In addition to the indices of distribution provided in Table 23 and Table 24, Figure 6 shows histograms of the distribution with a normal curve which best fit on it, box-plots, and Q-Q plots for Previous Problem Solving Ability in physics among the three groups, namely PIMS, MS, and control group. Figure 6 further visually compare Previous Problem Solving Ability in Physics among the three groups and demonstrates the normality of distribution.

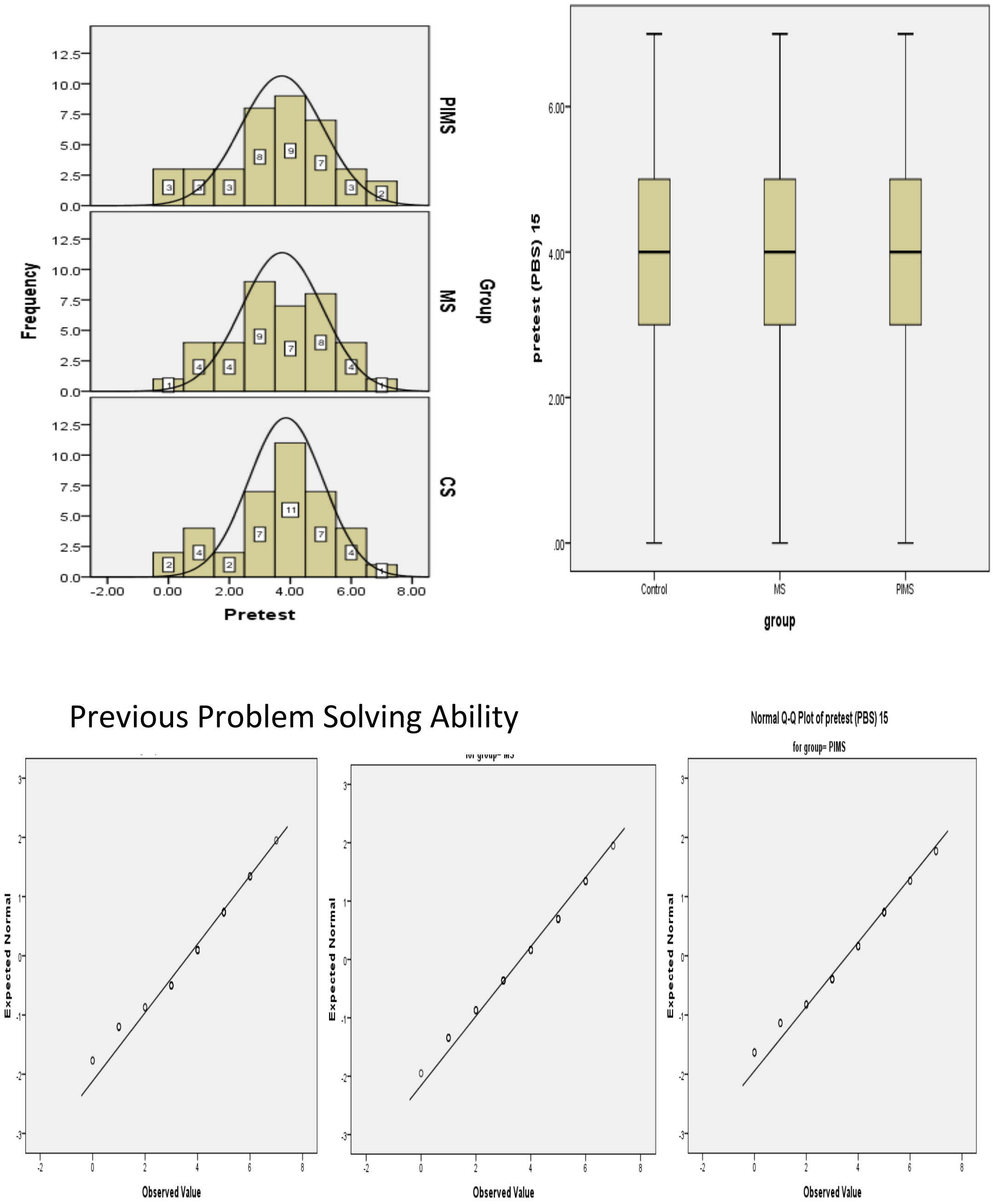


Figure 6: Histograms with the normal curve which best fit on them, Box-plots, and Normal Q-Q plots of the distribution of scores of Previous Problem Solving Ability in PIMS, MS and Control (CS) groups.

Figure 6 demonstrates the distribution of scores of Previous Problem Solving Ability of the three groups, PIMS, MS, and control, as indicated by the indices of skewness and kurtosis. Figure 6 further show the normality of distribution for Previous Problem Solving Ability in physics of the three groups as indicated by their Shapiro-Wilk statistic. Nearly bell shaped distribution in the histograms of PIMS, MS and control groups for Previous Problem Solving Ability further evidence the assumption of normality.

Figure 6 also shows box-plots that are symmetric with median line in approximately the centre of the box and with symmetric whiskers longer than the subsections of the center box suggests that the scores of Previous Problem Solving Ability in physics have a normal distribution for each of the groups (PIMS, MS, and control). The quintile- quintile plots (Q-Q plots) for each group shows that the scores for Previous Problem Solving Ability in physics fit the normal distribution. Though two points in each group appear not to fit on the normal, they do not deviate much from the normal and need not be considered as outliners.

In short as revealed by indices of Skewness, Kurtosis, Shapiro-Wilk statistic, Levene statistic, histograms, box-plots, and Q-Q plots the distribution of scores of Previous Problem solving Ability in Physics for the three groups, PIMS, MS, and control group were normal, and the variances among the three groups were homogeneous.

Indices of Analogical Problem Solving Ability

The important statistical indices namely., mean, median, mode, standard deviation, skewness, and kurtosis, of the dependent variable Analogical Problem Solving Ability were computed for each of the two

Experimental groups (PIMS group and MS group) and the Control Group (CS group). These are presented in Table 25.

Table 25

Indices of Analogical Problem Solving Ability of Higher Secondary School Students in Physics

Groups	Mean	Median	Mode	SD	Skewness	SE	Kurtosis	SE
PIMS	9.89	10	12	3.37	-.33	.38	-.88	.75
MS	9.16	10	10	2.46	-.49	.38	-.49	.75
Control	6.03	6	6	1.91	1.02	.38	2.13	.75

Table 25 reveals that mean (9.89), median (10), mode (12) of Analogical Problem Solving Ability in PIMS are nearly equal. The skewness (-.33, *SE*=.38) and kurtosis (-.88, *SE*=.75) indicate slightly negatively skewed, platy kurtic distribution of Analogical Problem Solving Ability in PIMS group. Likewise, mean (9.16), median (10), mode (10) of Analogical Problem Solving Ability in MS are nearly equal. The skewness (-.49, *SE*=.38) and kurtosis (-.49, *SE*=.75) indicate slightly negatively skewed, platy kurtic distribution of Analogical Problem Solving Ability in MS group. Similarly, mean (6.03), median (6), mode (6) of Analogical Problem Solving Ability in control group are nearly equal. The skewness (1.02, *SE*=.38) and kurtosis (2.13, *SE*=.75) indicate highly positively skewed, lepto kurtic distribution of Analogical Problem Solving Ability in control group. It can also be seen that the mean scores of Analogical Problem Solving Ability for the experimental groups, PIMS (*M*=9.89, *SD*=3.37) and MS (*M*=9.16, *SD*=2.46) groups is higher than that for the Control group (*M*=6.03, *SD*=1.91) after the intervention. The ratio between skewness and its standard error, and that between kurtosis and its standard error are less than 1.96 for each of the groups, PIMS, and MS. Therefore it can be concluded that the distribution of scores for Analogical Problem Solving Ability in physics of each of the groups, PIMS, and MS are normal at 95percent confidence (Kim, 2013). While the ratio between skewness and its standard error, and that between kurtosis and its standard error are more than 1.96 for control group. Therefore it can be concluded that the distribution of scores for Analogical Problem Solving Ability in physics of the control group is not normal. Further the mean scores of Analogical Problem Solving Ability for PIMS (*M*=9.89, *SD*=3.37) and MS (*M*=9.16, *SD*=2.46) are almost equal in spite of the difference in treatment given to the two groups.

To further assess the normality and homogeneity of variance of the distribution of scores of Analogical Problem Solving Ability in physics for PIMS, MS, and control group, Shapiro-Wilk test for normality and Levene test for homogeneity was done. The results of these tests are summarized in Table 26.

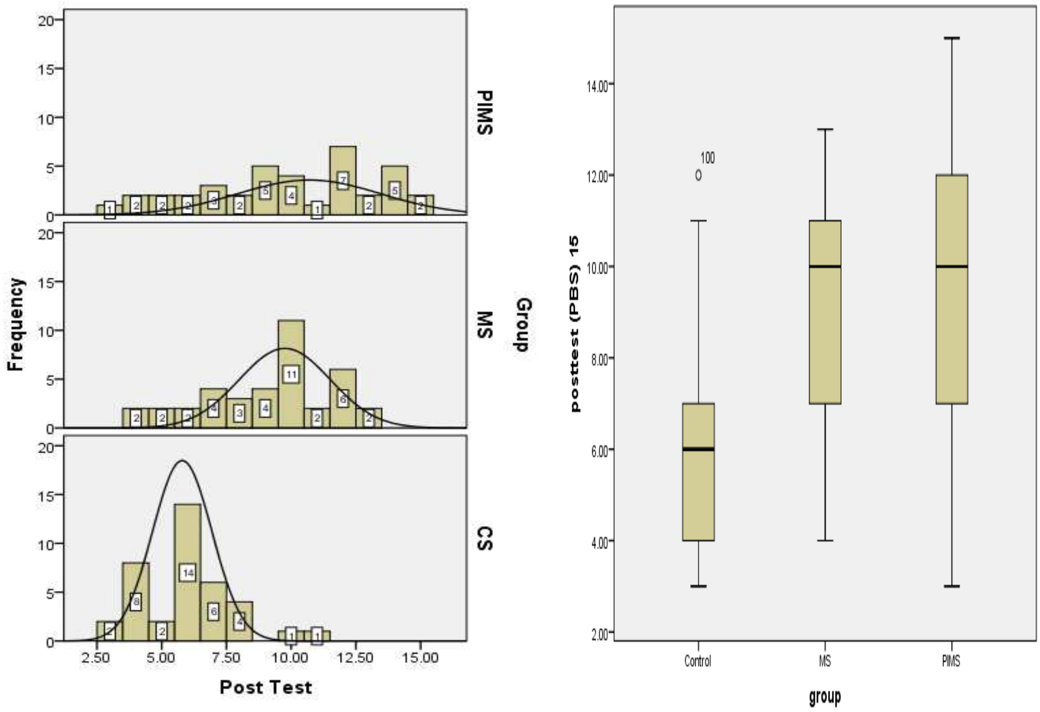
Table 26

Indices of Normality of Distribution (Shapiro-Wilk Statistic) and Homogeneity of Variance (Levene Statistic) of Analogical Problem Solving Ability in Physics of Higher Secondary School Students

Groups	Shapiro-Wilk statistic (S-W)	df	Levene statistic	df_1	df_2
PIMS	.95	38	8.96	2	111
MS	.94	38			
Control	.89	38			

From Table 26, the Shapiro-Wilk statistic of normality (*S*-*W*=.95, *df*=38, *p*>.05) suggest that normality is a reasonable assumption for Analogical Problem Solving Ability in physics of PIMS group. Similarly the Shapiro-Wilk statistic of normality (*S*-*W*=.94, *df*=38, *p*>.01) suggest that normality is a reasonable assumption for Analogical Problem Solving Ability in physics of MS group. The Shapiro-Wilk statistic of normality (*S*-*W*=.89, *df*=38, *p*<.01) suggest that Analogical Problem Solving Ability in physics of control group did not have a normal distribution. Table 26 also reveals that the variances of Analogical Problem solving Ability were significantly different for the three groups namely, PIMS, MS, and control, F (2,111) =8.96, p<.01. Therefore it can be concluded that the distribution of scores of Analogical Problem solving Ability in Physics for the two groups (PIMS, and MS) were normal, but for control group, the distribution of scores of Analogical Problem solving Ability in Physics deviates significantly from normal. Further the variances among the three groups for Analogical Problem solving Ability in Physics were not homogeneous. Therefore instead of Fisher's F, Welch's F was reported to find the effect of Metacognitive Strategy Instruction on Analogical Problem Solving Ability in Physics among Higher Secondary school students.

In addition to the indices of distribution provided in Table 25 and Table 26, Figure 7 shows histograms of the distribution with a normal curve which best fit on it, box-plots, and Q-Q plots for Analogical Problem Solving Ability in physics among the three groups, namely PIMS, MS, and control group. Figure 7 further visually compare Analogical Problem Solving Ability in Physics among the three groups and demonstrates the presence or absence of normality of distribution.



Analogical Problem Solving Ability

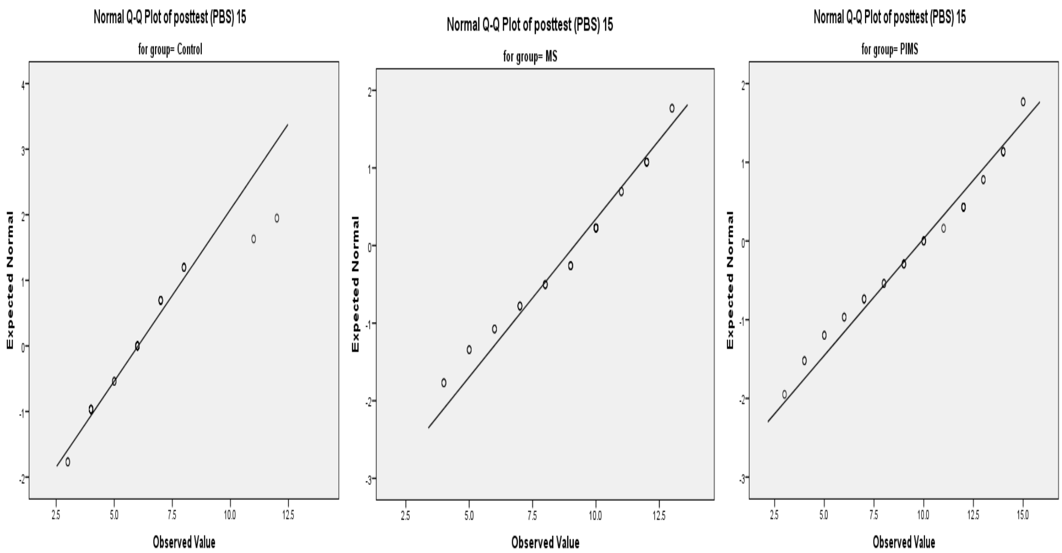


Figure 7: Histograms with the normal curve which best fit on them, Box-plots, and Normal Q-Q plots of the distribution of scores of Analogical Problem Solving Ability in PIMS, MS and Control (CS) groups.

Figure 7 demonstrates the distribution of scores of Analogical Problem Solving Ability of the three groups, PIMS, MS, and control, as indicated by the indices of skewness and kurtosis. Figure 7 further show the normality of distribution for Analogical Problem Solving Ability in physics of the three groups as indicated by their Shapiro-Wilk statistic. Nearly bell shaped distribution in the histograms of PIMS and MS for Analogical Problem Solving Ability further evidence the assumption of normality.

Figure 7 also shows box-plots that are symmetric with median line in approximately the centre of the box and with symmetric whiskers longer than the subsections of the center box suggests that the scores of Analogical Problem Solving Ability in physics have a normal distribution for each of the groups (PIMS, and MS). It can also be seen that the median of the control group lies much below that for the PIMS and MS group. This suggests that the median of Analogical Problem Solving Ability in physics for the PIMS and MS group may be significantly higher than that for the control group. The quintile- quintile plots (Q-Q plots) for PIMS and MS group shows that the scores for Analogical Problem Solving Ability in physics fit the normal distribution. Though three points in each group appear not to fit on the normal, they do not deviate much from the normal and need not be considered as outliners. Whereas, the Q-Q plot for the control group shows two outliners, deviating significantly from the normal.

In short as revealed by indices of Skewness, Kurtosis, Shapiro-Wilk statistic, histograms, box-plots, and Q-Q plots, the distribution of scores of Analogical Problem solving Ability in Physics for the two groups, PIMS and MS group were normal, while that for the control group was not normal. In addition, Levene test for homogeneity shows that the variances among the three groups were not homogeneous, necessitating the computation of Welch's F for the determination of effect of Metacognitive Strategy Instruction on analogical Problem Solving Ability in physics among Higher Secondary school students.

Indices of Problem Solving Skills in Physics

The important statistical indices viz., mean, median, mode, standard deviation, skewness, kurtosis of the dependent variable Problem Solving Skills in Physics were compared for each of the two Experimental groups (PIMS group and MS group) and the Control Group (CS group). These are presented in Table 27.

Table 27

Indices of Problem Solving Skills in Physics of Higher Secondary School Students

Groups	Mean	Median	Mode	SD	Skewness	SE	Kurtosis	SE
PIMS	8.16	8.5	10	2.64	-.30	.38	-.94	.75
MS	7.21	8	8	2.18	.04	.38	-.64	.75
Control	4.87	5	6	1.98	-.21	.38	.99	.75

Table 27 shows that mean (8.16), median (8.5), mode (10) of Problem Solving Skills in Physics in PIMS are nearly equal. The skewness (-.30, *SE*=.38) and kurtosis (-.94, *SE*=.75) indicate slightly negatively skewed, platy kurtic distribution of Problem Solving Skills in Physics in PIMS group. Likewise, mean (7.21), median (8), mode (8) of Problem Solving Skills in Physics in MS are nearly equal. The skewness (.04, *SE*=.38) and kurtosis (-.64, *SE*=.75) indicate slightly positively skewed, platy kurtic distribution of Problem Solving Skills in Physics in MS group. Similarly, mean (4.87), median (5), mode (6) of Problem Solving Skills in Physics of control group are nearly equal. The skewness (-.21, *SE*=.38) and kurtosis (-.99, *SE*=.75) indicate slightly negatively skewed, platy kurtic distribution of Problem Solving Skills in Physics in control group. It is also evident from the table that the mean scores of Problem Solving Skills in Physics is different for all the three groups namely, PIMS (*M*=8.16, *SD*=2.64), MS (*M*=7.21, *SD*=2.18), and Control (*M*=4.87, *SD*=1.98) groups. It is the highest for PIMS (*M*=8.16, *SD*=2.64) and least for Control (*M*=4.87, *SD*=1.98) group. The ratio between skewness and its standard error, and that between kurtosis and its standard error are less than 1.96 for each of the groups, PIMS, MS, and control. Therefore it can be concluded that the distribution of scores for Problem Solving Skills in Physics of each of the groups, PIMS, MS, and control are normal at 95percent confidence (Kim, 2013).

To further assess the normality and homogeneity of variance of the distribution of scores of Problem Solving Skills in Physics for PIMS, MS, and control group, Shapiro-Wilk test for normality and Levene test for homogeneity was done. The results of these tests are summarized in Table 28.

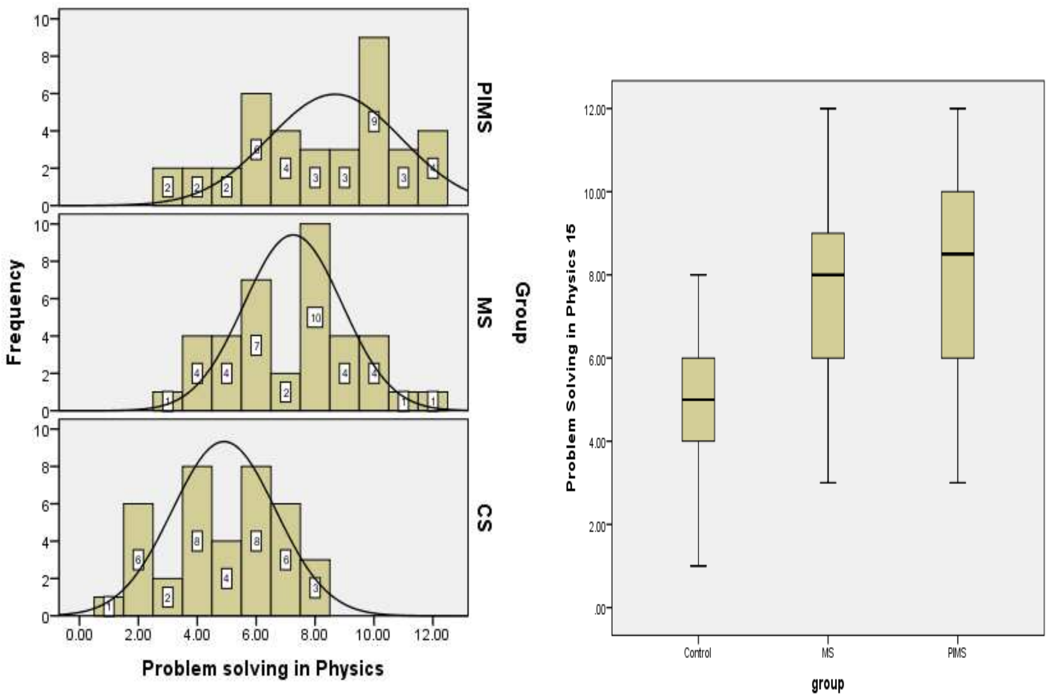
Table 28

Indices of Normality of Distribution (Shapiro-Wilk Statistic) and Homogeneity of Variances (Levene statistic) of Problem Solving Skills in Physics of Higher secondary School students

Groups	Shapiro-Wilk statistic (S-W)	df	Levene statistic	df_1	df_2
PIMS	.94	38			
MS	.96	38	2.64	2	111
Control	.94	38			

From Table 28, the Shapiro-Wilk statistic of normality (*S*-*W*=.94, *df*=38, *p*>.01) suggest that normality was a reasonable assumption for Problem Solving Skills in Physics of PIMS group. Similarly the Shapiro-Wilk statistic of normality (*S*-*W*=.96, *df*=38, *p*>.05) suggest that normality was a reasonable assumption for Problem Solving Skills in Physics of MS group. The Shapiro-Wilk statistic of normality (*S*-*W*=.94, *df*=38, *p*>.01) suggest that normality was a reasonable assumption for Problem Solving Skills in Physics of control group. Also for Problem Solving Skills in Physics, the variances were equal for the three groups namely, PIMS, MS, and control, F (2,111) =2.64, p>.05. Therefore it can be concluded that the distribution of scores of Problem solving Skills in Physics for the three groups, PIMS, MS, and control group were normal, and the variances among the three groups were homogeneous.

In addition to the indices of distribution provided in Table 27 and Table 28, Figure 8 shows histograms of the distribution with a normal curve which best fit on it, box-plots, and Q-Q plots for Problem Solving Skills in physics among the three groups, namely PIMS, MS, and control group. Figure 8 further visually compare Problem Solving Skills in Physics among the three groups and demonstrates the normality of distribution.



Problem Solving Skills in Physics

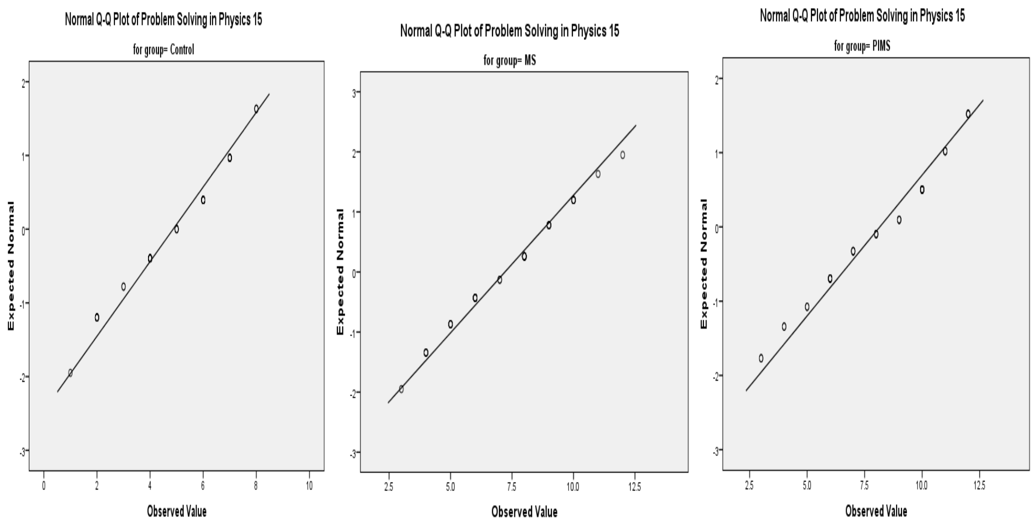


Figure 8: Histograms with the normal curve which best fit on them, Box-plots, and Normal Q-Q plots of the distribution of scores of Problem Solving Skills in Physics in PIMS, MS and Control (CS) groups.

Figure 8 demonstrates the distribution of scores of Problem Solving Skills in Physics of the three groups, PIMS, MS, and control, as indicated by the indices of skewness and kurtosis. Figure 8 further show the normality of distribution for Problem Solving Skills in physics of the three groups as indicated by their Shapiro-Wilk statistic. Nearly bell shaped distribution in the histograms of PIMS, MS and control groups for Problem Solving Skills in physics further evidence the assumption of normality.

Figure 8 also shows box-plots that are symmetric with median line in approximately the centre of the box and with symmetric whiskers longer than the subsections of the center box suggest that the scores of Problem Solving Skills in Physics have a normal distribution for each of the groups (PIMS, MS, and control). It can also be seen that the median of the control group lies much below that for the PIMS and MS group. This suggests that the median of Problem Solving Skills in Physics for the PIMS and MS group may be significantly higher than that for the control group. The quintile- quintile plots (Q-Q plots) for each group shows that the scores for Problem Solving Skills in Physics fit the normal distribution. Though a few points in each group appear not to fit on the normal, they do not deviate much from the normal and need not be considered as outliners.

In short as revealed by indices of Skewness, Kurtosis, Shapiro-Wilk statistic, Levene statistic, histograms, box-plots, and Q-Q plots the distribution of scores of Problem solving Skills in Physics for the three groups, PIMS, MS, and control group were normal, and the variances among the three groups were homogeneous.

Indices of the Use of Metacognitive Strategies in Problem Solving

The important statistical indices viz., mean, median, mode, standard deviation, skewness, kurtosis of the dependent variable Use of Metacognitive Strategies in Problem Solving were compared for each of the two Experimental groups (PIMS group and MS group). These are presented in Table 29.

Table 29

Indices of the Use of Metacognitive Strategies in Problem Solving of Higher Secondary School Students in Physics

Groups	Mean	Median	Mode	SD	Skewness	SE	Kurtosis	SE
PIMS	12.29	13	15	4.46	-.68	.38	-.16	.75
MS	9.58	9	12	3.39	-.37	.38	-.33	.75

Table 29 shows that mean (12.29), median (13), mode (15) of the Use of Metacognitive Strategies in Problem Solving in PIMS group are nearly equal. The skewness (-.68, *SE*=.38) and kurtosis (-.16, *SE*=.75) indicate slightly negatively skewed, platy kurtic distribution of the Use of Metacognitive Strategies in Problem Solving in PIMS group. Likewise, mean (9.58), median (9), mode (12) of the Use of Metacognitive Strategies in Problem Solving in MS group are nearly equal. The skewness (-.37, *SE*=.38) and kurtosis (-.33, *SE*=.75) indicate slightly negatively skewed, platy kurtic distribution of Use of Metacognitive Strategies in Problem Solving in MS group. It is also evident from the table that the mean scores of the Use of Metacognitive Strategies in Problem Solving is different for the two experimental groups namely, PIMS (*M*=12.29, *SD*=4.46) ,and MS (*M*=9.58, *SD*=3.39) groups. The ratio between skewness and its standard error, and that between kurtosis and its standard error are less than 1.96 for each of the groups, PIMS and MS. Therefore it can be concluded that the distribution of scores for Use of Metacognitive Strategies in Problem Solving of each of the groups, PIMS and MS are normal at 95percent confidence (Kim, 2013).

To further assess the normality and homogeneity of variance of the distribution of scores of the Use of Metacognitive Strategies in Problem Solving for PIMS and MS groups, Shapiro-Wilk test for normality and Levene test for homogeneity was done. The results of these tests are summarized in Table 30.

Table 30

Indices of Normality of Distribution (Shapiro-Wilk Statistic) and Homogeneity of Variance (Levene statistic) of the Use of Metacognitive Strategies in Problem Solving in Physics of Higher Secondary School Students

Groups	Shapiro-Wilk statistic (S-W)	df	Levene statistic	df_1	df_2
PIMS	.94	38	3.47	1	74
MS	.97	38			

From Table 30, the Shapiro-Wilk statistic of normality ($S\text{-}W$=.94, df=38, p>.01) suggest that normality was a reasonable assumption for the Use of Metacognitive Strategies in Problem Solving of PIMS group. Similarly the Shapiro-Wilk statistic of normality ($S\text{-}W$=.97, df=38, p>.05) suggest that normality was a reasonable assumption for the Use of Metacognitive Strategies in Problem Solving of MS group. Also for the Use of Metacognitive Strategies in Problem Solving, the variances were equal for the two groups namely, PIMS and MS, F (1,74) =3.47, p>.05. Therefore it can be concluded that the distribution of scores of the Use of Metacognitive

Strategies in Problem Solving for the two groups, PIMS and MS are normal, and the variances among the two groups are homogeneous.

In addition to the indices of distribution provided in Table 29 and Table 30, Figure 9 shows histograms of the distribution with a normal curve which best fit on it, box-plots, and Q-Q plots for the Use of Metacognitive Strategies in Problem Solving among PIMS and MS. Figure 4.4 further visually compare the Use of Metacognitive Strategies in Problem Solving among the two groups and demonstrates the normality of distribution.

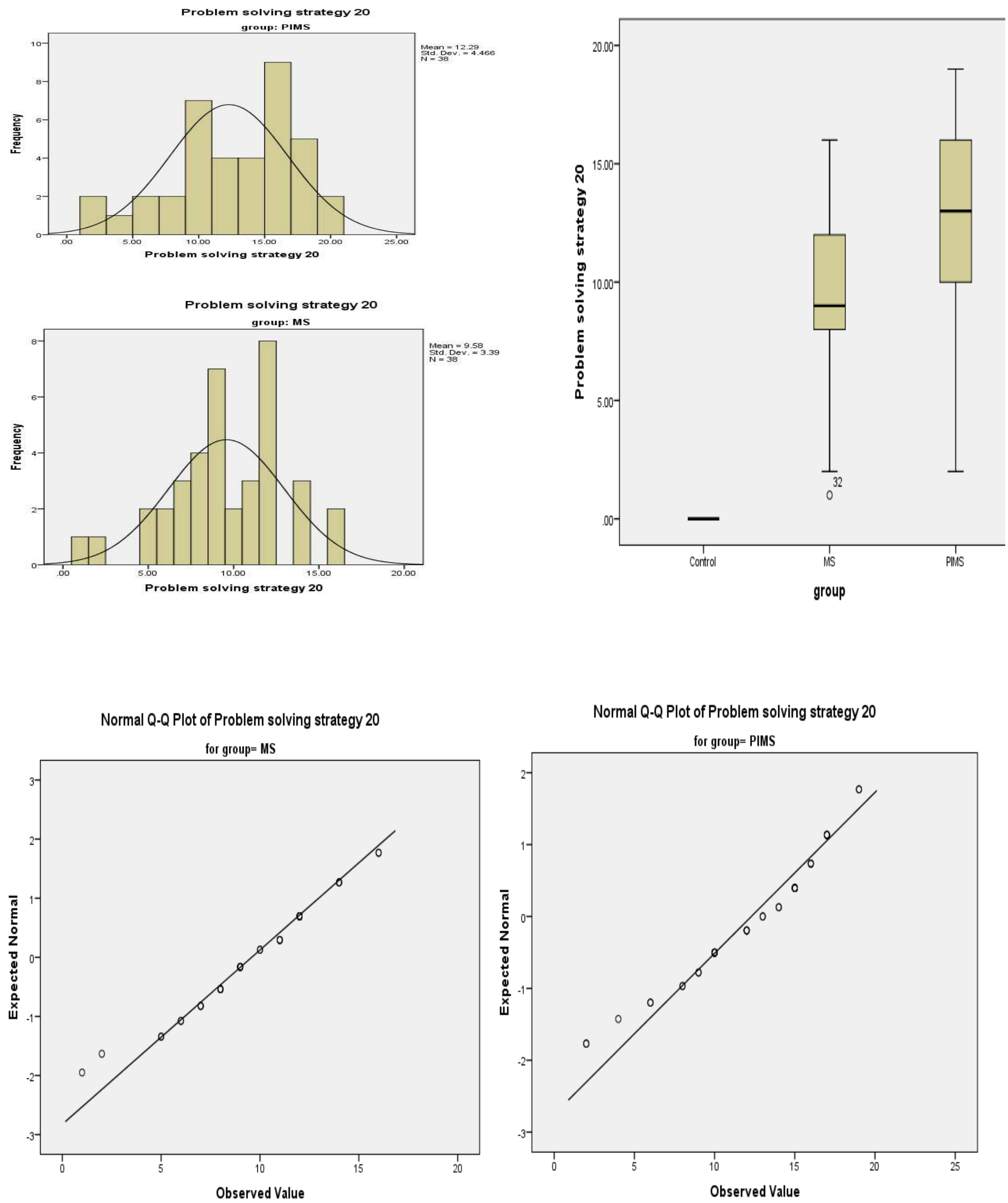


Figure 9: Histograms with the normal curve which best fit on them, Box-plots, and Normal Q-Q plots of the distribution of scores of the Use of Metacognitive Strategies in Problem Solving in Physics in PIMS, MS and Control (CS) groups.

Figure 9 demonstrates the distribution of scores of the Use of Metacognitive Strategies in Problem Solving of the two groups, PIMS and MS, as indicated by the indices of skewness and kurtosis. Figure 9 further show the normality of distribution for the Use of Metacognitive Strategies in Problem Solving in Physics of PIMS and MS groups as indicated by their Shapiro-Wilk statistic. Nearly bell shaped distribution in the histograms of PIMS and MS for the Use of Metacognitive Strategies in Problem Solving further evidence the assumption of normality.

Figure 9 also shows box-plots that are symmetric with median line in approximately the centre of the box and with symmetric whiskers longer than the subsections of the center box suggests that the scores of the Use of Metacognitive Strategies in Problem Solving have a normal distribution for each of the groups (PIMS and MS). It can also be seen that the median of the MS group lies much below that for the PIMS group. This suggests that the median of the Use of Metacognitive Strategies in Problem Solving Skills for PIMS group may be significantly higher than that for MS group. The quintile-quintile plots (Q-Q plots) for each group shows that the scores for the Use of Metacognitive Strategies in Problem Solving fit the normal distribution. Though a few points in each group appear not to fit on the normal, they do not deviate much from the normal and need not be considered as outliners.

In short as revealed by indices of Skewness, Kurtosis, Shapiro-Wilk statistic, Levene statistic, histograms, box-plots, and Q-Q plots the distribution of scores of the Use of Metacognitive Strategies in Problem Solving for PIMS and MS group are normal, and the variances among the groups are homogeneous.

Effectiveness of Metacognitive Strategy Instruction on Problem Solving Skills in Physics

The major analysis was done to test the hypotheses set for the study. Specifically, analysis was done to test whether there is significant effect of Metacognitive Strategy Instruction on Problem Solving Skills in Physics among higher secondary school students. This was done by examining the level of effectiveness of the three instructional strategies namely, Metacognitive Strategy (MS), Peer Interacting Metacognitive Strategy (PIMS), and the Conventional Strategy (CS). Major analysis was also done with the intention to estimate the relative efficiency of the four component skills of metacognitive strategy namely, representing the problem, planning the solution, implementing the plan, and evaluating the result, on problem solving skills in physics.

The major analysis of the study is presented in the following sections.

I) Effect of Metacognitive Strategy Instruction on Analogical Problem Solving Ability of Higher Secondary School Students in Physics

To answer the question, can Metacognitive Strategy Instruction [Peer Interacting Metacognitive Strategy (PIMS) Instruction and Metacognitive Strategy (MS) Instruction] significantly improve Analogical Problem Solving Ability of Higher Secondary School Students in Physics?, analysis of variance of the Analogical Problem Solving Ability in the three groups were carried out.

Mean scores of Analogical Problem Solving Ability were compared among PIMS, MS and Control (CS) groups using one – way ANOVA to check whether there exists any significant difference among the three groups after the intervention. Results of ANOVA are presented in Table 31.

Table 31

ANOVA of Analogical Problem Solving Ability by Levels of Metacognitive Strategy Instruction among Higher Secondary School Students in Physics

Source of Variance	SS	df	MS	F
Between Groups	320.65	2	160.32	
Within Groups	777.61	111	1.01	22.89**
Total	1098.25	113		

** indicate p<.01

Table 31 shows that the main effect of Metacognitive Strategy Instruction (Peer Interacting Metacognitive Strategy Instruction, Metacognitive Strategy Instruction, and Conventional strategy) on Analogical Problem Solving Ability is significant, F (2, 111)= 22.89, p< .01). Mean scores of Analogical Problem Solving Ability differ significantly among the PIMS (*M*=9.89, *SD*=3.37), MS (*M*=9.16, *SD*=2.46) and Control (*M*=5.97, *SD*=1.91) groups.

a) Comparison of mean scores of analogical problem solving ability of higher secondary school students in physics

One – way analysis of variance revealed that Analogical Problem Solving Ability differ significantly among the three groups (PIMS, MS and Control). To find out between which of these groups this difference exists and to answer the question can Peer Interacting Metacognitive Strategy Instruction develop analogical problem solving skills better than Metacognitive Strategy Instruction?, test of significance of difference between mean scores were carried out. The results of the test of significance of difference between mean scores are presented in Table 32.

Table 32

Comparison of Mean Scores of Analogical Problem Solving Ability of Higher Secondary School Students in Physics by Levels of Metacognitive Strategy Instruction

Groups	Mean	SD	SE_{mean}	Critical Ratio
PIMS (N=38)	9.89	3.37	.54	6.16**
Control (N=38)	6.03	1.91	.31	
MS (N=38)	9.16	2.46	.40	6.21**
Control (N=38)	6.03	1.91	.31	
PIMS (N=38)	9.89	3.37	.54	1.09^{NS}
MS (N=38)	9.16	2.46	.40	

** indicates p<.01
NS indicates not significant

Table 32 reveals that PIMS (*M*=9.89, *SD*=3.37) group shows significantly higher levels of Analogical Problem Solving Ability than Control (*M*=6.03, *SD*=1.91) group, *t*(74)=6.16, *p*< .01. MS (*M*=9.16, *SD*=2.46) group shows significantly higher levels of Analogical Problem Solving Ability than Control (*M*=6.03, *SD*=1.91) group, *t*(74)=6.21, *p*< .01. PIMS (*M*=9.89, *SD*=3.37) and MS (*M*=9.16, *SD*= 2.46) groups did not differ significantly on Analogical Problem Solving Ability, *t*(74)=1.09, *p* =NS

It is evident from the results that PIMS and Control groups differ significantly in the Analogical Problem Solving Ability. The significantly higher mean scores for Analogical Problem Solving Ability of the PIMS group suggest that Analogical Problem Solving Ability is higher in PIMS group than in the Control group. So it can be held that the students of PIMS group solve analogical problems more than the students of Control group. This further means that Peer Interacting Metacognitive Strategy Instruction is more effective in developing Analogical Problem Solving Ability in Physics than Conventional Strategy, where students are instructed problem solving without metacognitive monitoring.

Table 32 further shows that MS and Control groups differ significantly in the Analogical Problem Solving Ability. The significantly higher mean scores for Analogical Problem Solving Ability of the MS group evidence that Analogical Problem Solving Ability is higher in MS group than in the Control group. So it can be held that the students of MS group solve analogical problems more than the students of Control group. This further means that Metacognitive Strategy Instruction is more effective in developing Analogical Problem Solving Ability than Conventional Strategy, where students are instructed problem solving without metacognitive monitoring.

Table 32 in addition shows that PIMS and MS groups do not differ significantly in their Analogical Problem Solving Ability. So it can be held that both the PIMS and MS groups have almost the same level of Analogical Problem Solving Ability after the intervention, and that Peer Interaction in Metacognitive Strategy Instruction does not make any significant improvement in Analogical Problem Solving Ability over and above Metacognitive Strategy Instruction without Peer Interaction.

b) Effect size of metacognitive strategy instruction on analogical problem solving ability of higher secondary school students in physics

The comparison of means showed that the mean scores of Analogical Problem Solving Ability are significantly higher for the two experimental (PIMS and MS) groups than the Control group. So it is confirmed that the experimental interventions (Peer Interacting Metacognitive Strategy Instruction and Metacognitive Strategy Instruction) significantly improve Analogical Problem Solving Ability of the two experimental (PIMS and MS) groups in comparison to the Conventional Strategy, where students are instructed problem solving without metacognitive monitoring. Now the questions to be answered are ‘how much effect Peer Interacting Metacognitive Strategy Instruction has on Analogical Problem Solving Ability in Physics compared to the Conventional Strategy?’ and ‘how much effect Metacognitive Strategy Instruction has on Analogical Problem Solving Ability compared to the Conventional Strategy?’. To answer these questions three indices for effect size, namely ‘Cohen d’, ‘η^2’ and ‘ω^2’ were computed. Details of the analysis are summarized in Table 33.

Table 33

Effectiveness of Peer Interacting Metacognitive Strategy Instruction and Metacognitive Strategy Instruction on Analogical Problem Solving Ability in Physics of Higher Secondary School Students

Groups	Mean	SD	Cohen d	Source of Variance	SS	df	MS	F	η^2	ω^2
PIMS Control	9.89 6.03	3.37 1.91	2.02	Between Within Total	284.33 554.55 838.88	1 74 75	284.33 7.494	37.94**	.34	.33
MS Control	9.16 6.03	2.46 1.91	1.64	Between Within Total	186.33 358.03 544.36	1 74 75	186.23 4.84	38.51**	.34	.33
PIMS MS	9.89 9.16	3.37 2.46	.30	Between Within Total	10.32 642.63 652.95	1 74 75	10.32 8.68	1.19[NS]	.02	.02

** indicates p<.01

NS indicates no significance

Table 33 reveals that Peer Interacting Metacognitive strategy has a strong effect on Analogical Problem Solving Ability, Cohen d = 2.02.The effect of Peer Interacting Metacognitive Strategy Instruction on Analogical Problem Solving Ability in PIMS (*M*=9.89, *SD*=3.37) and Control (*M*=6.03, *SD*=1.91) groups is highly significant, $F(1)=37.94$, $p<.001$.The 'η^2'(.34) indicates a very large effect size for the Peer Interacting Metacognitive Strategy Instruction on Analogical Problem Solving Ability with 34percent of the variation in Analogical Problem Solving Ability between PIMS and Control group accorded to the Peer Interacting Metacognitive Strategy Instruction. Further effect size in terms of ω^2 (.33) also shows that 33percent of the variation in Analogical Problem Solving Ability between PIMS and Control group can be more accurately attributed to Peer Interacting Metacognitive Strategy Instruction.

Table 33 further reveals that Metacognitive strategy have a strong effect on Analogical Problem Solving Ability, Cohen d = 1.64. The effect of Metacognitive strategy Instruction on Analogical Problem Solving Ability in MS (*M*=9.16, *SD*=2.46) and Control (*M*=6.03, *SD*=1.91) groups is highly significant, $F(1)=38.51$, $p<.001$.The 'η^2' (.34) indicates a very large effect size for the Metacognitive Strategy Instruction on Analogical Problem Solving Ability with34.2percent of the variation in Analogical Problem Solving Ability between MS and Control group accorded to the Metacognitive Strategy Instruction. Further, effect size in terms of ω^2 (.33) shows that 33percent of the variation in Analogical Problem Solving Ability between MS and Control group can be more accurately attributed to Metacognitive Strategy Instruction.

Table 33 further reveals that there is only modest effect, Cohen d=.30, of Peer Interaction on Analogical Problem Solving Ability of higher secondary school students in physics. The variation in mean scores of Analogical Problem Solving Ability in PIMS (*M*=9.89, *SD*=3.37) and MS (*M*=9.16, *SD*=2.46) groups are not significant, *F*(1)=1.188, *p*=NS. In other words Metacognitive Strategy Instruction has the same effect irrespective of the class room setting. . This implies the strategy is effective in enhancing Analogical Problem Solving Ability both in the presence and absence of peer interaction among the students.

c) Discussion on effect of metacognitive strategy instruction on analogical problem solving ability of higher secondary school students in physics

Peer Interacting Metacognitive Strategy Instruction and Metacognitive Strategy Instruction without Peer Interaction had very strong effect on analogical problem solving ability of higher secondary school students in physics. About one third of the improvement in analogical problem solving ability of students can be accorded to the Metacognitive Strategy Instruction in the presence or absence of Peer Interaction. This is evidenced by the fact that students who were taught in Metacognitive Strategy Instruction out-scored their counterparts who were not taught in Metacognitive Strategy Instruction in a test on physics problems from the same content dealt in the class room during instruction irrespective of the presence or absence of collaborative group work.

It is also observed that there is no appreciable difference in the test performance among those students who worked in small groups and those who worked individually in the classroom. So it can be concluded that

Metacognitive Strategy Instruction is equally effective in enhancing content specific problem solving ability both in collaborative class room settings and in the absence of collaboration. Now, it's time to see whether these skills in solving familiar problems will transfer to solving problems from other areas of physics.

II) Effect of Metacognitive Strategy Instruction on Problem Solving Skills of Higher Secondary School Students in Physics

To answer the question can Metacognitive Strategy Instruction [Peer Interacting Metacognitive Strategy (PIMS) Instruction and Metacognitive Strategy (MS) Instruction] significantly improve Problem Solving Skills of Higher Secondary School Students in Physics, analysis of variance of Problem Solving Skills in Physics in the three groups namely, PIMS, MS, and control group were carried out.

Mean scores of Problem Solving Skills in Physics were compared among PIMS, MS and Control (CS) groups using one – way ANOVA to check whether there exists any significance difference among the three groups after the intervention. Results of ANOVA are presented in Table 34.

Table 34

ANOVA of Problem Solving Skills by Levels of Metacognitive Strategy Instruction among Higher Secondary School Students in Physics

Source of Variance	SS	df	MS	F
Between Groups	217.91	2	108.96	20.94**
Within Groups	577.71	111	5.20	
Total	795.62	113		

** indicate $p<.01$

Table 34 shows that the main effect of Instruction (Peer Interacting Metacognitive Strategy Instruction, Metacognitive Strategy Instruction, and Conventional Strategy) on Problem Solving Skills in Physics is significant, $F(2, 111) = 20.94$, $p < .01$. Mean scores of Problem Solving Skills in Physics differ significantly among the PIMS (*M*=8.16, *SD*=2.64), MS (*M*=7.21, *SD*=2.18) and Control (*M*=4.87, *SD*=1.98) groups.

a) Comparison of mean scores of problem solving skills of higher secondary school students in physics

One – way analysis of variance revealed that Problem Solving Skills in Physics differ significantly among the three groups (PIMS, MS and Control). To find out between which of these groups this difference exists and to answer the question can Peer Interacting Metacognitive Strategy Instruction develop problem solving skills in physics better than Metacognitive Strategy Instruction?, test of significance of difference between mean scores were carried out. The results of the test of significance of difference between mean scores are presented in Table 35.

Table 35

Comparison of Mean scores of Problem Solving Skills of Higher Secondary School Students in Physics by Levels of Metacognitive Strategy Instruction

Groups	Mean	SD	Sd. Error Mean	Critical Ratio
PIMS (N=38)	8.16	2.64	.42	6.16**
Control (N=38)	4.87	1.98	.32	
MS (N=38)	7.21	2.18	.35	4.90**
Control (N=38)	4.87	1.98	.32	
PIMS (N=38)	8.16	2.64	.42	1.71*
MS (N=38)	7.21	2.18	.35	

** indicates p<.01
* indicates p<.05

Table 35 reveals that PIMS (*M*=8.16, *SD*=2.64) group shows significantly higher levels of Problem Solving skills in Physics than Control (*M*=4.87, *SD*=1.98) group, $t(74)=6.16$, $p< .01$. MS (*M*=7.21, *SD*=2.18) group shows significantly higher levels of Problem Solving Skills in Physics than Control (*M*=4.87, *SD*=1.98) group, $t(74)=4.90$, $p< .01$. PIMS (*M*=8.16, *SD*=2.64) group shows significantly higher levels of Problem Solving skills in Physics than MS (*M*=7.21, *SD*=2.18) group, $t(74)=1.71$, $p< .05$.

It is evident from the results that PIMS and Control groups differ significantly in the Problem Solving Skills in Physics. The significantly higher mean scores for Problem Solving Skills in Physics of the PIMS group evidence that Problem Solving Skills in Physics is higher in PIMS group than in the Control group. So it can be held that the students of PIMS group solve novel physics problems more than the students of Control group. This further means that Peer Interacting Metacognitive Strategy Instruction is more effective in developing Problem Solving Skills in Physics than Conventional Strategy, where students are taught problem solving without metacognitive monitoring.

Table 35 in addition reveals that MS and Control groups differ significantly in the Problem Solving Skills in Physics. The significantly higher mean scores for Problem Solving Skills in Physics of the MS group evidence that Problem Solving Skills in Physics is higher in MS group than in the Control group. So it can be held that the students of MS group solve novel physics problems more than the students of control group. This further means that Metacognitive Strategy Instruction is more effective in developing Problem Solving Skills in Physics than Conventional Strategy.

Table 35 in addition shows that PIMS and MS groups differ significantly in the Problem Solving Skills in Physics. The significantly higher mean scores for Problem Solving Skills in Physics of the PIMS group evidence that Problem Solving Skills in Physics is higher in PIMS group than in the MS group. So it can be held that the students of PIMS group solve novel physics problems more than the students of MS group. This further means that Metacognitive Strategy Instruction is more effective in developing Problem Solving Skills in Physics that can be transferred to other areas in physics if done in an environment facilitating peer interaction.

b) Effect size of metacognitive strategy instruction on problem solving skills of higher secondary school students in physics

The comparison of means showed that the mean scores of Problem Solving Skills in Physics are significantly higher for the two experimental (PIMS and MS) groups than the Control group. So it is confirmed that the experimental interventions (Peer Interacting Metacognitive Strategy Instruction and Metacognitive Strategy Instruction) significantly improve Problem Solving Skills in Physics of the two experimental (PIMS and MS) groups in comparison to the conventional strategy, where students are taught problem solving without metacognitive monitoring. Now the questions to be answered are ‘how much the effect of Peer Interacting Metacognitive Strategy Instruction has on Problem Solving Skills in Physics compared to the Conventional Instructional Strategy?’, ‘how much the effect of Metacognitive Strategy Instruction has on Problem Solving Skills in Physics compared to the Conventional Instructional Strategy?’ and ‘how much is the effect of Peer Interacting on Problem Solving Skills in Physics?’. Three indices for effect size, namely 'Cohen d', 'η^2' and 'ω^2' were computed. Details of the analysis are summarized in Table 36.

Table 36

Effectiveness of Peer Interacting Metacognitive Strategy Instruction and Metacognitive Strategy Instruction on Problem Solving Skills in Physics of Higher Secondary School Students

Groups	Mean	SD	Cohen d	Source of Variance	SS	df	MS	F	η^2	ω^2
				Between	205.59	1	205.59			
PIMS Control	8.16 4.87	2.64 1.98	1.66	Within	401.40	74	5.42	37.90**	.34	.33
				Total	606.99	75				
				Between	104.22	1	104.22			
MS Control	7.21 4.87	2.18 1.98	1.18	Within	320.66	74	4.33	24.05**	.24	.23
				Total	424.88	75				
				Between	17.05	1	17.05			
PIMS MS	8.16 7.21	3.37 2.18	.44	Within	433.37	74	5.86	2.09	.04	.02
				Total	450.42	75				

** indicates p<.01

Table 36 reveals that Peer Interacting Metacognitive strategy has a strong effect on Problem Solving Skills in Physics, Cohen d = 1.66.The effect of Peer Interacting Metacognitive Strategy on Problem Solving Skills in Physics in PIMS (*M*=8.16, *SD*=2.64) and Control (*M*=4.78, *SD*=1.98) groups is highly significant, $F(1)=37.90$, $p<.001$.The 'η^2' (.34) indicates a very large effect size for the Peer Interacting Metacognitive Strategy Instruction on Problem Solving Skills in Physics with 34percent of the variation in Problem Solving Skills in Physics between PIMS and Control group accorded to the Peer Interacting Metacognitive Strategy Instruction. Further effect size in terms of ω^2 (.33) shows that 33percent of the variation in Problem Solving Skills in Physics between PIMS and Control group can be more accurately attributed to the Peer Interacting Metacognitive Strategy Instruction.

Table 36 further reveals the following details about the effectiveness of Metacognitive Strategy on Problem Solving Skills of higher secondary school students in Physics. Metacognitive strategy has a strong effect on Problem Solving Skills in Physics, Cohen d = 1.18. The variation in mean scores of Problem Solving Skills in Physics in MS (*M*=7.21, *SD*=2.18) and Control (*M*=4.87, *SD*=1.98) groups is highly significant, $F(1)=24.05$, $p<.001$.The 'η^2' (.24) indicates a very large effect size for the Metacognitive Strategy Instruction on Problem Solving Skills in Physics with 24percent of the variation in Problem Solving Skills in Physics between MS and Control group can be accorded to Metacognitive Strategy Instruction. Further, ω^2 (.23) shows that 23percent of the variation in Problem Solving Skills in Physics between MS and Control group can be more accurately attributed to Metacognitive Strategy Instruction.

Table 36 further reveals that there is only modest effect, Cohen d=.44, on Peer Interaction on Problem Solving Skills of higher secondary school students in physics. The variation in Problem Solving Skills in Physics in PIMS (*M*=8.16, *SD*=2.64) and MS (*M*=7.21, *SD*=2.18) groups is significant, $F(1)=2.09$, $p<.10$.The 'η^2'(.04) indicates a very small effect size for the Peer Interacting Metacognitive Strategy Instruction on Problem Solving Skills in Physics with only 4percent of the variation in Problem Solving Skills in Physics between PIMS and MS group accorded to the Peer Interaction during instruction. Further ω^2 (.02) shows that only 2percent of the variation in Problem Solving Skills in Physics between PIMS and MS group can be more accurately attributed to the Peer Interaction during instruction.

c) Discussion on effect of metacognitive strategy instruction on problem solving skills of higher secondary school students in physics

Peer Interacting Metacognitive Strategy Instruction and Metacognitive Strategy Instruction without Peer Interaction had very strong effect on problem solving skills of higher secondary school students in physics. This is evidenced by the fact that students who were taught in Metacognitive Strategy Instruction significantly out-performed their counterparts who were not taught in Metacognitive Strategy Instruction in a test on physics problems from contents that were not dealt in the class room during instruction.

About 34percent of the improvement in problem solving skills of students can be accorded to the Metacognitive Strategy Instruction in the presence of Peer Interaction and about 24percent of the improvement in problem solving skills in physics can be accorded to Metacognitive Strategy Instruction in the absence of peer interaction. There is some difference in the test performance among those students who worked in small groups and those who worked without group interaction in the classroom. Students in the experimental group who had group discussions (PIMS) exhibited more problem solving skills in novel problem situations than the students in the experimental group who did not make group discussions (MS). But the difference in effect caused by collaborative group work is very small, about 2percent.

It can be concluded that Metacognitive Strategy Instruction is highly effective in enhancing transfer of problem solving skills to other content domains of physics both in collaborative and individual class room settings. Though small, there is an advantage of group interaction during

Metacognitive Strategy Instruction on the transfer of problem solving skills. Now it's time to see whether this advantage of peer interaction in transfer of problem solving skills is reflected in the use of metacognitive strategies during problem solving.

III) Effect of Peer Interaction on the Use of Metacognitive Strategies in Problem Solving of Higher Secondary School Students in Physics

To answer the question can Peer Interaction (Peer Interacting Metacognitive Strategy (PIMS) Instruction) significantly effect the Use of Metacognitive Strategies in Problem Solving of Higher Secondary School Students in Physics?, analysis of variance of the Use of Metacognitive Strategy Instruction were carried out.

Mean scores of the Use of Metacognitive Strategies in Problem Solving were compared among PIMS and MS groups using one – way ANOVA to check whether there exists any significance difference among the two groups after the intervention. Results of ANOVA are presented in Table 37.

Table 37

ANOVA of the Use of Metacognitive Strategies in Problem Solving in Physics by Levels of Metacognitive Strategy Instruction among Higher Secondary School Students

Source of Variance	SS	df	MS	F
Between Groups	139.59	1	139.59	8.88**
Within Groups	1163.08	74	15.717	
Total	1302.671	75		

** indicate p<.01

Table 37 shows that the main effect of Peer Interaction on Problem Solving Skills in Physics is significant, F (1,74)= 8.88, p< .01. Mean scores of the Use of Metacognitive Strategies in Problem Solving in Physics differ significantly among the PIMS (*M*=12.29, *SD*=4.46) and MS (*M*=9.58, *SD*=3.39) groups. The significantly higher mean scores for the Use of Metacognitive Strategies in Problem Solving for the PIMS group suggest that the Use of Metacognitive Strategies in Problem Solving is significantly higher in PIMS group than in the MS group. So it can be held that the students of PIMS group employ the steps followed during metacognitive strategy instruction while solving physics problems more than the students of MS group. This further means that if Metacognitive Strategy Instruction is provided in a class room where students work in small groups, they are more prone to follow the steps in metacognitive strategies in problem solving.

Now to answer the question 'how much effect Peer Interaction has on the Use of Metacognitive Strategies in Problem Solving Skills in Physics?', three indices for effect size, namely 'Cohen d', 'η^2' and 'ω^2' were computed. Details of the analysis are summarized in Table 38.

Table 38

Effectiveness of Peer Interaction on the Use of Metacognitive Strategies in Problem Solving Skills of Higher Secondary School Students in Physics

Groups	Mean	SD	Cohen d	Source of Variance	SS	df	MS	F	η^2	ω^2
				Between	139.59	1	139.59			
PIMS MS	12.29 9.58	4.46 3.39	.80	Within	1163.08	74	15.72	8.88**	.12	.09
				Total	1302.67	75				

** indicates p<.01

Table 38 reveals that Peer Interaction have a moderate effect on the Use of Metacognitive strategies in Problem Solving, Cohen d = .80.The effect of Peer Interacting Metacognitive Instruction on the Use of Metacognitive Strategies in Problem Solving in PIMS (*M*=12.29, *SD*=4.46) and MS (*M*=9.58, *SD*=3.39) groups are highly significant, $F(1)=8.88$, $p<.001$.The 'η^2'(.12) indicates a moderate effect size for the Peer Interaction on the Use of Metacognitive Strategies in Problem Solving with 12percent of the variation in the Use of Metacognitive Strategies in Problem Solving between PIMS and MS group accorded to the Peer Interaction. Further effect size in terms of ω^2 (.09) shows that 9percent of the variation in the Use of Metacognitive strategies in Problem Solving between PIMS and MS group can be more accurately attributed to Peer Interaction.

Discussion on effect of peer interaction on the use of metacognitive strategies in problem solving of higher secondary school students in physics

Peer Interaction has moderate effect on the use of metacognitive strategies during problem solving. There is some difference in the use of metacognitive strategies among those students who worked in small groups and those who worked individually in the classroom. It is also revealed that students who worked collaborate used the metacognitive strategies more fluently than their counter parts who did not work in groups, though both the groups were taught in Metacognitive Strategy Instruction. But only one-tenth of the difference in use of metacognitive strategy during problem solving can be accorded to collaborative group work. So it can be concluded that students acquire the component skills in problem solving (steps in metacognitive strategy) significantly if Metacognitive Strategy Instruction is done in a frame work of peer interaction.

Analysis reveals that Metacognitive Strategy Instruction is highly effective in enhancing transfer of problem solving skills to other content domains of physics both in collaborative and individual class room settings. Yet, students in the experimental group who had group discussions (PIMS) exhibited more problem solving skills in novel problem situations than the students in the experimental group who did not have group discussions (MS). It is also found that students attain the component skills in problem solving (steps in metacognitive strategy) more noticeably if Metacognitive Strategy Instruction is done with a support of peer interaction. Therefore to see how far these component skills vary among the two experimental groups (PIMS and MS groups) and to estimate the relative efficiency of the four component skills of Metacognitive Strategy on Problem Solving Skills namely, Representing the problem, Planning a solution, Implementing the plan, and Evaluating the solution, a comparison of these component skills was done among PIMS and MS groups.

IV) Relative Efficiency of the Four Component Skills of Metacognitive Strategy on Problem Solving Skills of Higher Secondary School Students in Physics

To find the relative efficacy of the four Component Skills of Metacognitive Strategy in problem solving viz., Representing the problem, Planning the solution, Implementing the plan, and, Evaluating the solution on overall Problem Solving Skills in Physics, Multiple Regression Analysis of these four Component Skills of Metacognitive Strategy in Problem Solving viz., Representing the problem, Planning the solution, Implementing the plan, and, Evaluating the solution and overall Problem Solving Skills in Physics was done. Before multiple regression analysis the important statistical indices viz., mean, median, mode, standard deviation, skewness, kurtosis and Shapiro-Wilk statistic of the four Component Skills of Metacognitive Strategy in Problem Solving viz., Representing the problem, Planning the solution, Implementing the plan, and, Evaluating the solution were computed for PIMS and MS groups. The indices of skewness, kurtosis, and Shapiro-Wilk statistic was then used to analyse the normality of distribution of the scores for the four component skills of metacognitive strategy in problem solving viz., Representing the problem, Planning the solution, Implementing the plan, and, Evaluating the solution. The details are summarised in Table 39.

Table 39

Indices of Distribution of the Four Component Skills of Metacognitive Strategies in Problem Solving in Physics of Higher Secondary School Students in PIMS and MS Groups

Component Skills	Group	Mean	Median	Mode	SD	Skewness[a]	Kurtosis[b]	Shapiro-Wilk statistic[c] (S-W)
Representing	PIMS	3.60	4.00	4.00	1.13	-1.53	1.58	.68
	MS	3.42	4.00	4.00	1.13	-.92	1.12	.88
Planning	PIMS	3.66	4.00	5.00	1.36	-1.03	.81	.85
	MS	2.66	3.00	3.00	1.60	-.12	-1.05	.92
Implementing	PIMS	2.66	2.00	1.00	1.77	.15	-1.50	.86
	MS	2.00	2.00	1.00	1.04	.00	-.87	.90
Evaluating	PIMS	2.26	2.00	1.00	1.48	.04	-1.07	.92
	MS	1.53	2.00	2.00	.83	-.09	-.41	.87

[a]SE = .38
[b]SE = .75
[c]df = 38

Table 39 reveals that mean (3.60), median (4.00), and mode (4.00) of the skill for Representing the problem in PIMS group are nearly equal. The indices of skewness (-1.53, *SE* = .38) and kurtosis (1.58, *SE* = .75) indicate negatively skewed, lepto kurtic distribution of the scores for the skill of

Representing the problem in PIMS group. The ratio between skewness and its standard error is less than 1.96 indicating that the distribution of scores for the skill of representing the problem in PIMS group is normal at 95percent confidence. The ratio between kurtosis and its standard error is more than 1.96 indicating that the distribution of scores for the skill of representing the problem in PIMS group is not normal at 95percent confidence. The Shapiro-Wilk statistic of normality (S-W=.68, df=38, p<.01) indicate that normality is not a reasonable assumption for the skill of Representing the problem in PIMS group. Likewise, mean (3.42), median (4.00), and mode (4.00) of the skill for Representing the problem in MS group are nearly equal. The indices of skewness (-.92, *SE* = .38) and kurtosis (1.12, *SE* = .75) indicate negatively skewed, lepto kurtic distribution of the scores for the skill of Representing the problem in MS group. The ratio between skewness and its standard error is more than 1.96 indicating that the distribution of scores for the skill of representing the problem in MS group is not normal at 95percent confidence. The ratio between kurtosis and its standard error is less than 1.96 indicating that the distribution of scores for the skill of representing the problem in MS group is normal at 95percent confidence. The Shapiro-Wilk statistic of normality (S-W=.88, df=38, p<.01) indicate that normality is not a reasonable assumption for the skill of Representing the problem in MS group.

Table 39 further reveals that mean (3.66), median (4.00), and mode (5.00) of the skill for Planning the solution in PIMS group are nearly equal. The indices of skewness (-1.03, *SE* = .38) and kurtosis (.81, *SE* = .75) indicate negatively skewed, lepto kurtic distribution of the scores for the skill of Planning the solution in PIMS group. The ratio between skewness and its standard error is more than 1.96 indicating that the distribution of scores for the skill of representing the problem in PIMS group is not normal at

95percent confidence. The ratio between kurtosis and its standard error is less than 1.96 indicating that the distribution of scores for the skill of representing the problem in PIMS group is normal at 95percent confidence. The Shapiro-Wilk statistic of normality (S-W=.85, df=38, p<.01) indicate that normality is not a reasonable assumption for the skill of Planning the solution in PIMS group. Likewise, mean (2.66), median (3.00), and mode (3.00) of the skill for Planning the solution in MS group are nearly equal. The indices of skewness (-.12, *SE* = .38) and kurtosis (-1.05, *SE* = .75) indicate slightly negatively skewed, platy kurtic distribution of the scores for the skill of Planning the solution in MS group. The ratio between skewness and its standard error is less than 1.96 indicating that the distribution of scores for the skill of planning the solution in MS group is normal at 95percent confidence. The ratio between kurtosis and its standard error is less than 1.96 indicating that the distribution of scores for the skill of planning the solution in MS group is normal at 95percent confidence. The Shapiro-Wilk statistic of normality (S-W=.92, df=38, p>.01) indicate that normality is a reasonable assumption for the skill of Planning the solution in MS group.

Table 39 also reveals that mean (2.66), median (2.00), and mode (1.00) of the skill for Implementing the plan in PIMS group are nearly equal. The indices of skewness (.15, *SE* = .38) and kurtosis (-1.50, *SE* = .75) indicate slightly positively skewed, platy kurtic distribution of the scores for the skill of Implementing the plan in PIMS group. The ratio between skewness and its standard error is less than 1.96 indicating that the distribution of scores for the skill of Implementing the plan in PIMS group is normal at 95percent confidence. The ratio between kurtosis and its standard error is more than 1.96 indicating that the distribution of scores for the skill of Implementing the plan in PIMS group is not normal at 95percent confidence. The Shapiro-Wilk statistic of normality (S-W=.86, df=38, p<.01) indicate that normality is not a reasonable assumption for the skill of Implementing the plan in PIMS group. Likewise, mean (2.00), median (2.00), and mode (1.00) of the skill for Implementing the plan in MS group are nearly equal. The indices of skewness (.00, *SE* = .38) and kurtosis (-.87, *SE* = .75) indicate non-skewed, platy kurtic distribution of the scores for the skill of Implementing the plan in MS group. The ratio between skewness and its standard error is less than 1.96 indicating that the distribution of scores for the skill of implementing the plan in MS group is normal at 95 percent confidence. The ratio between kurtosis and its standard error is less than 1.96 indicating that the distribution of scores for the skill of implementing the plan in MS group is normal at 95 percent confidence. The Shapiro-Wilk statistic of normality (S-W=.90, df=38, p<.01) indicate that normality is not a reasonable assumption for the skill of Implementing the plan in MS group.

Table 39 reveals that mean (2.26), median (2.00), and mode (1.00) of the skill for Evaluating the solution in PIMS group are nearly equal. The indices of skewness (.04, *SE* = .38) and kurtosis (-1.07, *SE* = .75) indicate slightly positively skewed, platy kurtic distribution of the scores for the skill of Evaluating the solution in PIMS group. The ratio between skewness and its standard error is less than 1.96 indicating that the distribution of scores for the skill of evaluating the solution in PIMS group is normal at 95percent confidence. The ratio between kurtosis and its standard error is less than 1.96 indicating that the distribution of scores for the skill of evaluating the solution in PIMS group is normal at 95percent confidence. The Shapiro-Wilk statistic of normality (S-W=.92, df=38, p>.01) indicate that normality is a reasonable assumption for the skill of Evaluation of solution in PIMS group. Likewise, mean (1.53), median (2.00), and mode (2.00) of the skill for Evaluation of solution in MS group are nearly equal. The indices of skewness (-.09, *SE* = .38) and kurtosis (-.41, *SE* = .75) indicate slightly negatively skewed, platy kurtic distribution of the scores for the skill of Evaluating the solution in MS group. The ratio between skewness and its standard error is less than 1.96 indicating that the distribution of scores for the skill of evaluating the solution in MS group is normal at 95percent confidence. The ratio between kurtosis and its standard error is less than 1.96 indicating that the distribution of scores for the skill of evaluating the solution in PIMS group is normal at 95percent confidence. The Shapiro-Wilk statistic of normality (S-W=.87, df=38, p<.01) indicate that normality is not a reasonable assumption for the skill of Evaluating the solution in MS group.

Analysis for normality of the distributions of scores of each of the component skills of metacognitive strategies in problem solving viz., Representing the problem, Planning the solution, Implementing the plan, and Evaluating the solution reveals that distribution of scores of each of these component skills when taken separately in PIMS and MS group deviate significantly from normal distribution. Therefore, the results of multiple regression analysis done by taking each of these component skills of metacognitive strategies in problem solving as separate variables may not be generalisable to the population. Still, in order to answer the question, which component skills in metacognitive strategy of problem solving viz., Representing the problem, Planning the solution, Implementing the plan, and Evaluating the solution contribute significantly to the problem solving skills in physics in students instructed on Metacognitive Strategy, computation of Pearson’s r for pairs of component skills of metacognitive strategies in problem solving followed by multiple regression analysis was done.

To answer the question, is there a significant positive relationship between component skills of metacognitive strategy in problem solving viz., Representing the problem, Planning the solution, Implementing the plan, and, Evaluating the solution and the overall problem solving skills in physics in students instructed on Metacognitive Strategy, first order Pearson's r were calculated.

First order Pearson's r between pairs of Component Skills of Metacognitive Strategies in Problem Solving viz., Representing the problem, Planning the solution, Implementing the plan, and Evaluating the solution and between each of these four component skills of Metacognitive Strategies in Problem Solving and overall Problem Solving Skills in Physics was determined. Pair wise first order Pearson's r between component skills of Metacognitive Strategies in Problem Solving and over all Problem Solving Skills in Physics are presented as an inter-correlation matrix in Table 40.

Table 40

Inter-correlation (Pearson's r) Matrix of Component Skills of Metacognitive Strategies in Problem Solving and Overall Problem Solving Skills in Physics among Higher Secondary School Students after Metacognitive Strategy Instruction

Skills	Representing	Planning	Implementing	Evaluating	Overall Problem Solving Skills
Representing	--	--	--	--	--
Planning	.55	--	--	--	--
Implementing	.35	.34	--	--	--
Evaluating	.42	.55	.48	--	--
Overall Problem Solving Skills	.58	.66	.57	.64	--

Note: All the Pearson's r s are significant, $p<.01$

Table 40 reveals that there is significant positive correlation between pairs of Component Skills of Metacognitive strategies in Problem Solving viz., Representing the problem, Planning the solution, Implementing the plan, and Evaluating the solution. Representing the problem and Planning the solution are significantly correlated, $r = .55$, $p<.01$. Representing the problem and Implementing the plan are significantly correlated, $r = .35$, $p<.01$. Representing the problem and Evaluating the solution are significantly correlated, $r = .42$, $p<.01$. Planning the solution is significantly correlated with Implementing the plan, $r = .34$, $p<.01$. Planning the solution is significantly correlated with Evaluating the solution, $r =.55$, $p<.01$. Implementing the plan is significantly correlated with Evaluating the solution, $r=.48$, $p<.01$. It can be noted that Pearson's coefficient of correlation between pairs of Component Skills of Metacognitive Strategies of Problem Solving viz., Representing the problem, Planning the solution, Implementing the plan, and Evaluating the solution ranges between .55-.34, showing substantial or marked relationship.

Table 40 also reveals that there is significant positive correlation between each of the Component Skills of Metacognitive Strategies in Problem Solving viz., Representing the problem, Planning the solution, Implementing the plan, and Evaluating the solution and overall Problem Solving Skills in Physics. Representing the problem is significantly correlated with overall Problem Solving Skills in Physics, $r = .58$, $p<.01$. Planning the solution is significantly correlated with overall Problem Solving Skills in Physics, $r = .66$, $p<.01$. Implementing the plan is significantly correlated with overall Problem Solving Skills in Physics, $r = .57$, $p<.01$. Evaluating the solution is significantly correlated with overall Problem Solving Skills in Physics, $r = .64$, $p<.01$. It can be noted that Pearson's coefficient of correlation between each of the Component Skills of Metacognitive Strategies in Problem

Solving viz., Representing the problem, Planning the solution, Implementing the plan, and Evaluating the solution and overall Problem Solving Skills in Physics rages between .66-.57. These correlations are higher than that between pairs of Component Skills of Metacognitive Strategies in Problem Solving viz., Representing the problem, Planning the solution, Implementing the plan, and Evaluating the solution.

Now the question is which component skills in metacognitive strategy of problem solving viz., Representing the problem, Planning the solution, Implementing the plan, and Evaluating the solution contribute significantly to the problem solving skills in physics in students instructed on Metacognitive Strategy? To answer this question, multiple regression analysis was used to analyze if the various Component Skills of Metacognitive Strategies in Problem Solving, namely, Representing the problem, Planning the Solution, Implementing the Plan, and Evaluating the Solution significantly contributed to Problem Solving Skills in Physics. It was also determined what percentage of the variance in Problem Solving Skills among the students of PIMS and MS group could be explained by the contributing Component Skills of Problem Solving Strategy. The results of multiple regression analysis are summarized in Table 41.

Table 41

Relative Efficiency of the Four Component Skills of Metacognitive Strategies in Problem Solving Skills in Physics of Higher Secondary School Students

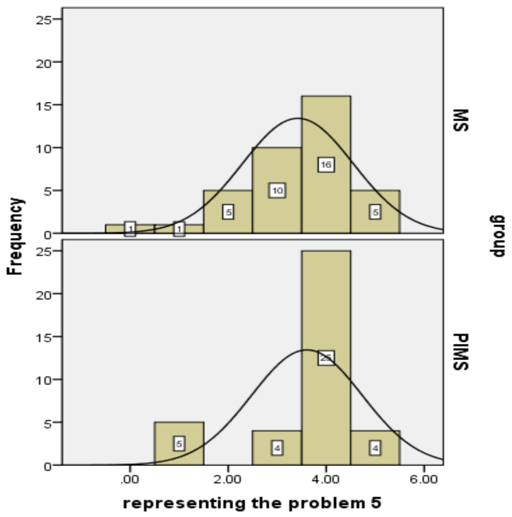
Component Skills	R	B	Sd. Error	β	t	r	β×r
Planning the Solution	.660	.445	.168	.283	2.630**	.527	.149
Implementing the Plan		.527	.159	.319	3.310**	.502	.160
Representing the Problem		.538	.235	.247	2.283*	.514	.127
$F(3,72) = 18.56^{**}$, $\sum \beta \times r = R^2 = .436$							

The results of regression indicate that three component skills of metacognitive strategy in problem solving viz., Planning the Solution, Implementing the Plan, and Representing the Problem explained 43.6percent of the variance in Problem Solving Skills in Physics (R^2 = .436, F (3, 72) = 18.56, p<.01) among the PIMS and MS groups. It was found that the skill of Planning the Solution significantly explained Problem Solving Skills in Physics (β=.283, p<.01) as did Implementing the Plan (β= .319, p<.01) and Representing the Problem (β=.247, p<.05). Evaluating the Solution did not contribute significantly to the variance in Problem Solving Skills in Physics among the PIMS and MS groups.

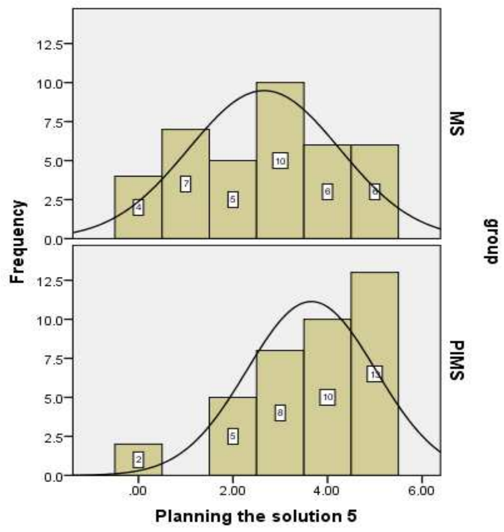
Discussion on relative efficiency of the four component skills of metacognitive strategy on problem solving skills of higher secondary school students in physics

Results of multiple regressions indicate that the component skills in problem solving strategy namely, Representing the Problem, Planning the Solution and Implementing the Plan contributed significantly to the overall Problem Solving Skills in Physics of the PIMS and MS group. The component skills in problem solving which was considered as the steps in metacognitive problem solving strategy like Representing the problem, Planning the solution, and Implementing the plan are significant contributors to overall problem solving skills in physics. Students who showed better performance in these component skills outperformed their counterparts. While, Evaluating the solution did not contribute significantly to overall problem solving skills in physics. The skill for planning the solution contributed to 15percent of the improvement in Problem solving Skills in Physics, the skill for implementing the plan contributed to 16percent of the improvement in Problem Solving Skills in Physics, and the skill for representing the problem contributed to 13percent of the improvement in Problem Solving Skills in Physics. The three Component Skills of Metacognitive Strategies in Problem Solving together contributed to 44percent of the improvement in Problem Solving Skills in Physics.

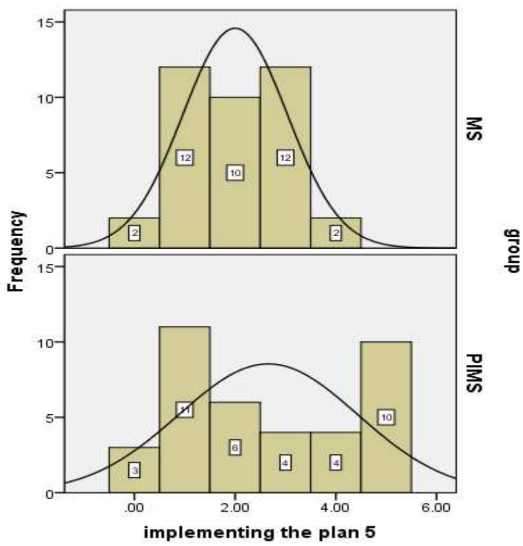
Figure 10 gives a graphical view for comparison between groups on the component skills of metacognitive strategies in problem solving namely, Representing the Problem, Planning the Solution, Implementing the Plan, and Evaluation of Results in PIMS and MS groups.



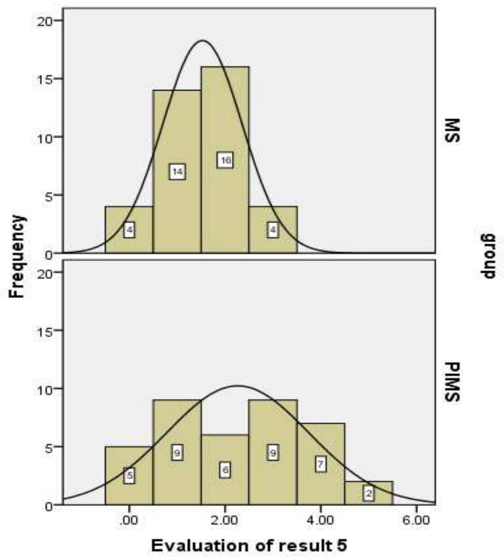
a)



b)



c)



d)

Figure 10: Histograms with the normal curve which best fit on them of the component skills in problem solving namely, Representing the Problem, Planning the Solution, Implementing the Plan, and Evaluation of Results in PIMS and MS groups

Figure 10 (a) provides a graphical view of the distribution of scores of the skill of representing the problem in PIMS and MS groups. Figure 10 (a) in addition shows that the frequency curves for the two groups have their peak at a score near to 4.00. The two groups have a similar distribution curve. It can be seen that both the groups have almost equally attained the skill for identifying explicitly the information specified and wanted in the problem and representing them on the basis of physics principles.

Figure 10 (b) provides a graphical view of the distribution of scores of the skill for planning the solution in PIMS and MS groups. Figure 10 (b) in addition shows that the peak of the frequency curves for PIMS is moved towards right, compared to that of the MS group. Further the frequencies are high for higher scores for the PIMS group. Majority of the students have scored well, which means they have attained the skill for developing an appropriate algorithm to solve the problem in PIMS group compared to the MS group.

Figure 10 (c) gives a graphical view of the distribution of scores of the skill for implementing the Plan in PIMS and MS groups. Figure 10 (c) shows that the peak of the frequency curves for PIMS is moved towards right, compared to that of the MS group. Further the maximum score attained by students in MS group is 4.00 with a frequency of 2, while 14 students in PIMS group have scored above 4.00. A large number of students in the PIMS group have scored maximum, which means that they have attained the skill for generating the solution from the given variables in the problem following the algorithm designed in the planning stage.

Figure 10 (d) gives a graphical view of the distribution of scores of the skill for evaluation of the result in PIMS and MS groups. Figure 10 (d) in addition shows that the distribution curves are normal. The peak value of the curve have moved a little towards the higher score side for the PIMS group. While the maximum score for Evaluation of the results obtained by the students of MS group is 3.00, with a frequency of 4, about 18 students in the PIMS group have scored above 3.00. Two students in the PIMS group have scored the maximum. These observations reveal that, student in PIMS group have attained a higher level of the skill for checking the correctness and logic of the obtained solution compared to the MS group.

Conclusion

Results show that before providing Metacognitive Strategy Instruction, students of both the experimental groups (PIMS and MS) and those of the control group were equivalent with respect to their problem solving ability (Previous Problem Solving Ability) in Physics.

After giving Metacognitive Strategy Instruction as an experimental intervention, students of both the experimental groups, those given Metacognitive Strategy Instruction supplemented by collaborative group work (PIMS group) and those not supplemented by collaborative group work (MS group) very high level of problem solving ability in content specific (Analogical Problem Solving Ability) and its transfer (Problem Solving Skills in Physics) compared to the control group who were taught by Conventional Strategy. Thus it can be concluded that the metacognitive strategy instruction is effective in enhancing problem solving skills irrespective of the classroom settings. This implies the strategy is effective both in the presence and absence of peer interaction among the students.

However, students in the experimental group who had group discussions (PIMS) exhibited more problem solving skills in novel problem situations than the students in the experimental group who did not have group discussions (MS). But the difference in effect caused by collaborative group work was very small.

Also, the students who had collaborative group work out performed their counterpart in component skills of Metacognitive Strategy in problem solving, but the difference in effect was only moderate.

This study further reveals that the component skills in problem solving which was considered as the steps in metacognitive problem solving strategy like Representing the problem, Planning the solution, and Implementing the plan are significant contributors to overall problem solving skills in physics. Students who showed better performance in these component skills outperformed their counterparts on problem solving in Physics. However, Evaluating the solution did not contribute significantly to overall problem solving skills in physics

In summary, the Metacognitive Strategy Instruction is effective in enhancing Problem Solving Skills in Physics both in a collaborative or individual classroom setting. It is the fostering of component skills in problem solving like Representing the Problem, Planning the Solution, and Implementing the Plan, which is more important than whether the students are working in groups or not.

Tenability of the Hypotheses

Tenability of the hypotheses formulated for the study were verified in view of the findings and are commented below.

1. Hypothesis 1 states that "Metacognitive Strategy Instruction (Peer Interacting Metacognitive Strategy Instruction (PIMS) and Metacognitive Strategy (MS) Instruction) has significant effect on analogical problem solving ability in Physics among Higher Secondary School students".

Analysis of data revealed that the main effect of Metacognitive Strategy Instruction (Peer Interacting Metacognitive Strategy Instruction, Metacognitive Strategy Instruction, and Conventional strategy) on Analogical Problem Solving Ability is significant ($p < .01$). Mean scores of Analogical Problem Solving Ability differ significantly among the PIMS, MS, and Control groups. Analysis of data also revealed that PIMS group shows significantly higher levels of Analogical Problem Solving Ability than Control group ($p < .01$) and MS group shows significantly higher levels of Analogical Problem Solving Ability than Control group ($p < .01$).

Hence the hypothesis that "Metacognitive Strategy Instruction (Peer Interacting Metacognitive Strategy Instruction (PIMS) and Metacognitive Strategy (MS) Instruction) has significant effect on analogical problem solving ability in Physics among Higher Secondary School students" is accepted.

2. Hypothesis 2 states that “Peer Interaction in Metacognitive Strategy Instruction will significantly enhance analogical problem solving ability in physics among Higher Secondary School students”.

Analysis of data reveals that PIMS and MS groups did not differ significantly on Analogical Problem Solving Ability (p =n.s).

Hence the hypothesis that “Peer Interaction in Metacognitive Strategy Instruction will significantly enhance analogical problem solving ability in physics among Higher Secondary School students.” is not accepted.

3. Hypothesis 3 states that “Metacognitive Strategy Instruction (Peer Interacting Metacognitive Strategy (PIMS) Instruction and Metacognitive Strategy (MS) Instruction) has significant effect on Problem Solving Skills in Physics among Higher Secondary School Students”.

Analysis of data reveals that the main effect of Metacognitive Strategy Instruction (Peer Interacting Metacognitive Strategy Instruction, Metacognitive Strategy Instruction, and Conventional Strategy) on Problem Solving Skills in Physics is significant ($p < .01$). Mean scores of Problem Solving Skills in Physics differ significantly among the PIMS, MS and Control groups. Analysis of data also shows that PIMS group shows significantly higher levels of Problem Solving skills in Physics than Control group ($p < .01$) and MS group shows significantly higher levels of Problem Solving Skills in Physics than Control group ($p < .01$).

Hence, the hypothesis that “Metacognitive Strategy Instruction (Peer Interacting Metacognitive Strategy (PIMS) Instruction and Metacognitive

Strategy (MS) Instruction) has significant effect on Problem Solving Skills in Physics among Higher Secondary School Students" is accepted.

4. Hypothesis 4 states that "Peer Interaction in Metacognitive Strategy Instruction will significantly enhance problem solving skills in physics among Higher Secondary School students".

Analysis of data shows that PIMS group shows significantly higher levels of Problem Solving skills in Physics than MS group ($p < .05$).

Hence the hypothesis that "Peer Interaction in Metacognitive Strategy Instruction will significantly enhance problem solving skills in physics among Higher Secondary School students" is accepted.

5. Hypothesis 5 states that "Peer Interaction in Metacognitive Strategy Instruction will significantly enhance the use of metacognitive strategies in problem solving in physics among Higher Secondary School students".

Analysis of data reveals that the main effect of Peer Interaction on Problem Solving Skills in Physics is significant ($p < .01$). Mean scores of the Use of Metacognitive Strategies in Problem Solving in Physics is significantly higher among the PIMS group than the MS group.

Hence the hypothesis that "Peer Interaction in Metacognitive Strategy Instruction will significantly enhance the use of metacognitive strategies in problem solving in physics among Higher Secondary School students" is accepted.

6. Hypotheses 6(i) to 9(iii) states that "The component skills in metacognitive strategy of problem solving viz.,

i. Representing the problem

ii. Planning the solution

iii. Implementing the plan

will contribute significantly to the problem solving skills in physics of the PIMS group and MS group”.

Analysis of data shows that the three component skills of metacognitive strategy in problem solving viz., Planning the Solution, Implementing the Plan, and Representing the Problem explained 43.6percent of the variance in Problem Solving Skills in Physics (R^2 = .436, F (3, 72) = 18.560, p<.01) among the PIMS and MS groups. It was found that the skill of Planning the Solution significantly explained Problem Solving Skills in Physics (β=.283, p<.01; % influence =14.9) as did Implementing the Plan (β= .319, p<.01; % influence = 16.0) and Representing the Problem (β=.247, p<.05; % influence =12.7).

Hence, the hypotheses that “The component skills in metacognitive strategy of problem solving viz.,

i. Representing the problem

ii. Planning the solution

iii. Implementing the plan

will contribute significantly to the problem solving skills in physics of the PIMS group and MS group” are accepted.

7. Hypothesis 6(iv) states that “The component skills in metacognitive strategy of problem solving viz., Evaluating the solution will contribute significantly to the problem solving skills in physics of the PIMS group and MS group”.

Analysis of data reveals that Evaluating the Solution did not contribute significantly to the variance in Problem Solving Skills in Physics among the PIMS and MS groups.

Hence the hypothesis that "The component skills in metacognitive strategy of problem solving viz., Evaluating the solution will contribute significantly to the problem solving skills in physics of the PIMS group and MS group" is not accepted.

Chapter V

SUMMARY, FINDINGS, AND SUGGESTIONS

- ***Restatement of the Problem***
- ***Variables in the Study***
- ***Hypotheses Tested***
- ***Methodology***
  - *Design of the Study*
  - *Sample Used*
  - *Tools and Techniques Used*
  - *Statistical Analyses*
- ***Major Findings***
- ***Conclusion***
- ***Educational Implications of the Study***
- ***Suggestions for Further Research***

This chapter presents the investigation in a nutshell. It includes a brief account of the various aspects of the research like variables, objectives, hypotheses and methodology. It also compiles the major findings and illumines a final conclusion about the investigation. It clarifies the educational implications of the study and provides some suitable suggestions for further research.

Restatement of the Problem

"Effectiveness of a Metacognitive Strategy Instruction on Problem solving Skills in Physics among Higher Secondary School Students in Kerala"

Variables in the study

The study is quasi-experimental. It employs independent variables, dependent variables and control variable.

Independent Variables

Independent variables of this study are the three strategies of instruction, viz.,

1. Metacognitive Strategy
2. Peer Interacting Metacognitive Strategy
3. Conventional Strategy

Dependent variables

The effectiveness of the independent variables on problem solving skills in physics is studied. The study identified seven dependent variables, namely,

1. Analogical Problem Solving Ability
2. Problem Solving Ability in Physics
3. Use of Metacognitive Strategy for Problem Solving

This has four sub variables, namely,

1. Representing the Problem Situation
2. Planning the Solution
3. Implementing the Plan
4. Evaluation of Solution

Control variable

All the three groups were matched based on their Previous Problem Solving Ability. Hence the control variable in this study is the previous problem solving ability of pupils.

Hypotheses Tested

This study tested the following hypotheses;

1. Metacognitive Strategy Instruction (Peer Interacting Metacognitive Strategy Instruction (PIMS) and Metacognitive Strategy (MS) Instruction) has significant effect on analogical problem solving ability of Higher Secondary School students in Physics.
2. Peer Interaction in Metacognitive Strategy Instruction will significantly enhance analogical problem solving ability in physics among Higher Secondary School students.
3. Metacognitive Strategy Instruction (Peer Interacting Metacognitive Strategy (PIMS) Instruction and Metacognitive Strategy (MS)

Instruction) has significant effect on Problem Solving Skills of Higher Secondary School Students in Physics.

4. Peer Interaction in Metacognitive Strategy Instruction will significantly enhance problem solving skills in physics among Higher Secondary School students.
5. Peer Interaction in Metacognitive Strategy Instruction will significantly enhance the use of metacognitive strategies in problem solving in physics among Higher Secondary School students.
6. The component skills in metacognitive strategy of problem solving viz.,
   i. Representing the problem
   ii. Planning the solution
   iii. Implementing the plan and
   iv. Evaluating the solution

   will contribute significantly to the problem solving skills in physics of the PIMS group and MS group.

Methodology

The study is quasi-experimental. It employed a Non-equivalent Pre-test Post-test Control Group design to test the effectiveness of a metacognitive strategy instruction on the problem solving skills in physics among higher secondary school students of Kerala. This involved the development of the instructional strategy, teaching three units in physics using this instructional strategy, instructing the strategy directly to the students and testing its effectiveness.

Design of the Study

Non-equivalent pre-test post-test control group design:

G_1 : O_1 X_1 O_4 O_7 O_{10}

G_2 : O_2 X_2 O_5 O_8 O_{11}

G_3 : O_3 C_1 O_6 O_9

O_1, O_2 and O_3 are the Pre-tests on the dependent variable [Previous Problem Solving Ability in Physics]

O_4, O_5 and O_6 are the Post-tests, The Test on Analogical Problem Solving Ability in Physics.

O7, O8 and O9 are the Post-tests, The Test on Problem Solving Skills in Physics.

O10 and O11 are the Post-tests, The Test on Use of Metacognitive Strategies in Problem Solving, involving Component skills (representing the problem, planning the solution, implementing the plan, evaluating the solution)

G_1 is the First Experimental Group (PIMS group)

G_2 is the Second Experimental Group (MS group)

G_3 is the Control Group

X_1 is the Application of First Experimental Treatment (Peer Interacting Metacognitive Strategy)

X_2 is the Application of Second Experimental Treatment (Metacognitive Strategy)

C_1 is Application of Control Treatment (Conventional Strategy)

All the three groups are matched based on their previous problem solving ability.

Sample for the Present Study

Higher Secondary School Studnets of Kerala comprise the population of the study. Out of the fourteen districts in Kerala, Kozhikode district was randomly selected for the study. Three Higher Secondary Schools with students of comparable socio-economic status and educational background were choosen from Kozhikode district. These were Farook Higher Secondary School, Farook College; Government Ganapath Vocational Higher Secondary School, Feroke; and Government Vocational Higher Secondary School, Cheruvannur.

Sample used for standardization of tools

Out of three schools, two schools namely Farook Higher Secondary School and Government Ganapath Vocational Higher Secondary School were randomly assigned for providing sample for standardization of tools. Each of these schools had four grade 11 classes. There were around 50 students in each of these eight classrooms. From among the eight classes, three classes were randomly selected as standardization sample. In these three classes two (out of four) were from Government Ganapath Vocational Higher Secondary School and one class was (out of four) from Farook Higher Secondary School. In these three classes same tests were employed. Out of around 150 students who were administered the test, 112 students gave data which was complete in all respects. Therefore these 112 students were used as sample for standardization of tests.

Sample used in experiment

For conducting experiment, Government Vocational Higher Secondary School, Cheruvannur was randomly choosen. There were three grade 11 classes with around 50 students in each class. Pre-test (Previous Problem Solving Ability) were conducted in all the three classes. After matching the three groups on Previous Problem Solving Ability, 38 students each from the three classes were choosen for the intervention. The three groups of 38 studnets each were then randomly assigned into two experimental (PIMS and MS) and control (CS) group.

Tools and Techniques Used

The tools were developed and used to quantify the dependent and control variables. In total, four Tests on Problem Solving in the field of mechanics were developed and administered at different stages of the study. Two of these tests are parallel and were used as the pre-test and post-test of problem-solving ability. Thus, the three separate tests developed were the following.

1. Tests of Problem-Solving Ability (Two Parallel Forms; Previous Problem Solving Ability, and Analogical Problem Solving Ability in select unit where instruction was done).
2. Test on Problem Solving Skills in Physics (in higher secondary school physics in total) .
3. Test on Component Skills in Problem Solving (Use of Metacognitive Strategies in Problem Solving)

This diagnostic test consists of four sub-tests, viz.,

1. Test on the Ability to Represent Problem situation

2. Test on the Ability to Plan Problem Solving Procedure
3. Test on the Ability to Implement Problem Solving Procedure
4. Test on the Ability to Evaluate Solution to a Problem

In addition to the tools, a metacognitive strategy instruction was developed to enhance problem solving skills in physics among higher secondary school students. It consists of the following four phases:

I. Presentation of the Knowledge Domain

This phase involves three sub-phases.

1. Presentation of Concept map
2. Explanation of Concepts and their Relationships.
3. Exemplification of the use of concepts to solve problems

II. Presenting the Problem

III. Problem Solving Procedure

Problem solving procedure follows the steps viz.,

1. Surface Representation
2. Structure Representation
3. Planning the Solution
4. Implementing the Plan

IV. Metacognitive Analysis

Metacognitive Analysis involves three stages

1. Error Analysis
2. Monitoring the Procedure
3. Analogical Problem Solving

Statistical Analysis

The techniques of analysis of data employed in this study are the following.

1. Analysis of Variance (One-way)
2. Test of Significance of means (One-tailed)
3. Effect Size analysis
4. Multiple Regression Analysis

Major Findings

The major findings of the study, derived s answers for the four research questions, set at the begning of the studyare listed below with appropriate explanatory headlines.

1. ***Metacognitive Strategy Instruction [Peer Interacting Metacognitive Strategy (PIMS) Instruction and Metacognitive Strategy (MS) Instruction] significantly improve Analogical Problem Solving ability in Physics among Higher Secondary School Students.***

   i. The main effect of Metacognitive Strategy Instruction (Peer Interacting Metacognitive Strategy Instruction, Metacognitive Strategy Instruction, and Conventional strategy) on Analogical Problem Solving Ability is significant ($p < .01$). Mean scores of Analogical Problem Solving Ability differ significantly among the PIMS, MS, and Control groups.

   ii. PIMS group shows significantly higher levels of Analogical Problem Solving Ability than Control group ($p < .01$).

iii. MS group shows significantly higher levels of Analogical Problem Solving Ability than Control group ($p < .01$).

2. ***Peer Interaction during Metacognitive Strategy Instruction do not develop analogical problem solving ability over and above Metacognitive Strategy Instruction.***

   i. PIMS and MS groups did not differ significantly on Analogical Problem Solving Ability (p =n.s).

3. ***Metacognitive Strategy Instruction [Peer Interacting Metacognitive Strategy (PIMS) Instruction and Metacognitive Strategy (MS) Instruction] significantly improve Problem Solving Skills in Physics among Higher Secondary School Students.***

   i. The main effect of Metacognitive Strategy Instruction (Peer Interacting Metacognitive Strategy Instruction, Metacognitive Strategy Instruction, and Conventional Strategy) on Problem Solving Skills in Physics is significant ($p < .01$). Mean scores of Problem Solving Skills in Physics differ significantly among the PIMS, MS and Control groups.
   ii. PIMS group shows significantly higher levels of Problem Solving skills in Physics than Control group ($p < .01$).
   iii. MS group shows significantly higher levels of Problem Solving Skills in Physics than Control group ($p < .01$).

4. ***Peer Interaction during Metacognitive Strategy Instruction develops problem solving skills in physics over and above Metacognitive Strategy Instruction.***

   i. PIMS group shows significantly higher levels of Problem Solving skills in Physics than MS group ($p < .05$).

5. ***Peer Interaction [Peer Interacting Metacognitive Strategy (PIMS) Instruction] significantly improves the Use of Metacognitive Strategies in Problem Solving of Higher Secondary School Students (over Metacognitive Strategy Instruction).***

   i. The main effect of Peer Interaction on Problem Solving Skills in Physics is significant ($p < .01$).
   ii. Mean scores of the Use of Metacognitive Strategies in Problem Solving in Physics is significantly higher among the PIMS group than the MS group.

6. ***Component skills in metacognitive strategy of problem solving contributes significantly to the problem solving skills in physics in students instructed on Metacognitive Strategy.***

   i. The three component skills of metacognitive strategy in problem solving viz., Planning the Solution, Implementing the Plan, and Representing the Problem explained 43.6percent of the variance in Problem Solving Skills in Physics ($R^2 = .436$, $F(3, 72) = 18.560$, $p<.01$) among the higher secondary students who received metacognitive strategy instruction.
   ii. The skill for Planning the Solution significantly explained Problem Solving Skills in Physics (β=.283, $p<.01$; % influence = 14.9).
   iii. The skill for Implementing the Plan significantly explained Problem Solving Skills in Physics (β= .319, $p<.01$; % influence = 16.0).

iv. The skill for Representing the Problem significantly explained Problem Solving Skills in Physics (β=.247, p<.05; % influence = 12.7).

7. ***Component skill in metacognitive strategy of problem solving evaluating the solution do not contribute significantly to the problem solving skills in physics in students instructed on Metacognitive Strategy.***

   i. Evaluating the Solution did not contribute significantly to the variance in Problem Solving Skills in Physics among the PIMS and MS groups.

In view of the above findings hypotheses 1, 3, 4, 5, 6 (i), 6 (ii), and 6 (iii) are accepted. Hypotheses 2 and 6(iv) are not accepted.

Conclusion

From the analysis of data it can be concluded that, students of both the experimental groups (PIMS and MS) and those of the control group were not significantly different with respect to their problem solving ability (Previous Problem Solving Ability) in Physics before providing Metacognitive Strategy Instruction.

After a giving Metacognitive Strategy Instruction as an experimental intervention, students of both the experimental groups, those given Metacognitive Strategy Instruction supplemented by collaborative group work (PIMS group) and those not supplemented by collaborative group work (MS group) have appreciable improvement in their problem solving ability in content specific (Analogical Problem Solving Ability) and its transfer (Problem Solving Skills in Physics) compared to the control group who were taught by Conventional Strategy. Thus it can be concluded that the metacognitive strategy instruction is effective in enhancing problem solving skills irrespective of the classroom settings. This implies the metacognitive strategy is effective both in the presence and absence of peer interaction among the students.

Students in the experimental group who had group discussions (PIMS) exhibited more problem solving skills in novel problem situations than the students in the experimental group who worked individually (MS). But the difference in effect caused by collaborative group work was very small.

It is further evidenced that the students who had collaborative group work improved component skills of Metacognitive Strategy in problem solving moderately. Not only did Metacognitive Strategy Instruction develop component skill of Metacognitive Strategy among higher school students nut also the component skills pf Metacognitive Strategy contribute significantly to the problem solving skills in physics. Further collaborative group work during Metacognitive Strategy improves acquisition of these component skills over and above regular classroom instruction on Metacognitive Strategies.

The component skills in problem solving which were considered as the steps in metacognitive problem solving strategy viz., Representing the problem, Planning the solution, and Implementing the plan are significant contributors to overall problem solving skills in physics. Performance in these component skills is positively correlated to problem solving skills in physics. However, evaluating the solution did not contribute significantly to overall problem solving skills in physics

Thus the Metacognitive Strategy Instruction is effective in enhancing Problem Solving Skills in Physics both in a collaborative or individual classroom setting. It is the fostering of component skills in problem solving like Representing the Problem, Planning the Solution, and Implementing the

Plan, which is more important than whether the students are working in groups or not.

Educational Implications of the Study

Improving students' problem solving skills have been a major goal of science curriculam developers, science teachers and education researchers for decades. After developing a metacognitive strategy instruction for enhancing problem solving skills in physics and testing it, this study have demonstrated that the metacognitive strategy instruction is highly effective in improving both content specific and transfer problem solving skills in the classroom whether it facilitate peer collaboration or not. The suggestions made here are broad recommendations based on the finding from the study, the experiences derived by the researcher during the experimental intervention to enhance metacognitive startergy in higher secondary schools and also on the review of problem solving literature.

1. A conceptual understanding of the topic as a whole must be developed in students before they confront with the problems in school physics.

It could be wise not to expect the students to find the knowledge from different sources when they confront with the problem. Clear understanding of the problem situation and its relevant physical principles is possible only if the student have a well integrated knowledge of underlying concepts. This is a must especially in a complex domain like physics which is composed of several principles, technical details, generalisations, heuristics and other pieces of relevant information (Stevens &Palacio- Cayetano, 2003).A search for information will not allow the problem solving heuristics to appear fluently from problem solvers. The need for a well integrated domain knowledge before confronting the problem is also advocated by several researchers (Beyer, 1984; de Jong & Fergurson-Hessler, 1986; DeBono, 1983; Friege & Lind, 2006; Gorden & Gill, 1989; Jonassen, 2000; O'Neil & Schacter, 1999; Palumbo, 1990). The findings of the study support the principle that, domain specific problem solving abilities in physics is facilitated by clearer Metacognitive Strategy instruction.

2. Concept maps can be used as teaching and learning aids to develop well integrated domain knowledge.

This study has employed concept map for facilitating structuring of domain specific knowledge on the premise that the introduction of concept map can assist in the understanding of concepts and the relationships between them and also organize their understanding of a topic (Pendley, Bretz, & Novak, 1994). Though it is better to let the students construct their own concept maps after teaching a particular topic, teacher can construct the map and use that as a teaching aid to meet the time constraints in many a classrooms. Both as a teaching aid and activity aid concept map will help students understand the relationships between concepts and facilitate easy recall of learned concepts and their relationships. This study adds to an array of researches which proclaim the supportive role of concept maps in learning, teaching and problem solving (Abel & Freeze, 2006; Daley, Shaw, Balistrieri, Glasenapp, & Piacentine, 1999; Ertmer & Nour, 2007; Hinck, Webb, Sims-Gidden, Helton, Hope, Utley, Savinske, Fahey, & Yarbyough, 2006; Hsu, &Hsieh, 2005;Kinchin, Cobot, &Hay, 2008; Rendas, Fonseca, & Pinto, 2006; Wilgis & McConnell, 2008). Hence, Higher secondary school teachers may increasingly employ concept map as teaching aid and activity aids in science classrooms, as this strategy not only contributes to integration of domain knowledge but also facilitates the more important and difficult task of equipping students to solve problems.

3. Problem solving strategies should be explicitly taught to the students.

Conceptual knowledge though necessary is not a sufficient requirement for a successful problem solver. To become expert problem solvers, students should be explicitly taught about the different strategies to tackle problems. Such strategies may be different for different domains. In addition to declarative knowledge in a particular domain, procedural and situational knowledge should be given explicitly (Ferguson- Hessler & de Jong, 1990). The need to teach problem solving strategies are also campaigned by numerous researchers (Alibali, Phillips, & Fischer, 2009; Berge & Danielson, 2012; Bogard, Liu, & Chiang, 2013; Friege & Lind, 2006; Gaigher, Rogan, & Braun, 2007; Leonard, Dufresne, & Mestre, 1996; Lorenzo, 2005; Mayer, 1992; Park & Lee, 2004; Pol, Harskamp, Suhre, & Geodhart, 2008; Selcuk & Caliskan, 2008). This study has further demonstrated the effectiveness of explicit instruction of problem solving strategy and its transfer value in making students better problem solvers.

4. Encourage qualitative understanding of problems, rather than just giving numerical procedures to solve them.

The Metacognitive strategy instruction designed in this study required qualitative description of the problem situation as part of structure representation of the problem. Qualitative discussions were carried out while problems are solved on the chalkboard or while students work together during problem solving. Without a qualitative understanding of the problem situation, it is difficult for the students to realise the underlying phenomenon and physics principles required to solve them. The need for a careful and qualitative analysis of the problem situation is also advocated by numerous other researchers (Bacerra-Labra, Gra-Marti, & Torregrosa, 2012; Camacho & Good, 1989; Kosem & Ozdemir, 2014; Lee, Tang, Goh, & Chia, 2001; Neto & Valente, 1997; Park & Lee,2004). The qualitative understanding of problem through structure representation resulted in more than 10 percent improvement in problem solving in physics for higher secondary school students. Hence it is recommended to teach problems with qualitative understanding in a systamtic way.

5. Represent Physics problems in the form of diagrams to reduce memory overload.

One way to systematically buid up qualitative under standing of of the problem situation is through diagrams. Diagrams help learners to solve a problem effectively (Bauer & Johnson-Laird, 1993). The outcomes of this study also corroborate similar conclusions. Digrams also aids easy identification of known and unknown physical quantities and the physics principles that should be used to solve them. External representations can help a learner elaborate the problem statement, transform its ambiguous status to an explicit condition, constrain unnecessary cognitive workload, and create problem solutions (Jonassen & Strobel, 2006; Jonassen, 2005; Kim, 2012; Scaife & Rogers, 1996; Spector, 2010; Zhang & Norman, 1994; Zhang, 1997).

6. Give extensive practice of metacognitive skills in problem solving like, planning, monitoring progress, and verifying results.

Though Metacognitive strategy is reported in different formats by authors, there is a common sequence of events in such instruction. Identifiying this, Metacognitive skills in problem solving like planning the solution and implementing the plan are found to contribute significantly to problem solving skills in physics. Therefore it is recommended to give extensive practice of these metacognitive skills while solving problems in classrooms. Such metacognitive strategies are found to enhance problem solving skills by several researchers (Abdullah, 2006; Demircioglu, Argun, & Bulut, 2010; Jacobse & Harskamp, 2009; Jacobse & Harskamp, 2012; Lubin & Ge, 2012; Ozsoy, 2011; Schneider & Artelt, 2010). This study employed a four phased strategy, with planning, implementing, and evaluating the solution of a problem. The study shows that there is impact of these component skills on problem solving skills.

7. Give students practice of similar problem solving strategies across multiple contexts to encourage generalisation of strategies.

It is necessary to provide students with diverse, continual and prolonged problem solving experience. The sequence employed by this study was to provide an analogical problem following each problem solving illustration. Such problem-example alterations enhance generalisation of problem solving strategies as evidenced by fairly large impact on analogical as well as general problem solving in physics. This is also opined by other researchers (Atkinson, Derry, Renkl, & Wortham, 2000; Hausmann, Sande, & Vanheln, 2007).

8. Instruct Metacognitive strategy with collaborative group work whenever possible.

The present study reveals that collaborative group work or peer interaction has a small but significant additional effect on transferring problem solving skills attained to novel areas and in the use of metacognitive strategies while solving problems. Therefore it is recommended to facilitate collaborative group work during metacognitive strategy instruction whenever possible.

This study evidence that teaching well integrated domain knowledge as a whole using concept map before students confront with the problem, and explicit teaching of problem solving strategy with digramatic representation and qualitative descriptions followed by extensive practice of Metacognitive skills in a collaborative environment enhance problem solving skills. The experiences gain through this study and the demonstrated impact of strategies developed and advocated by this study, hell the investigator to recommend the following to the curriculam designers, teachers and other educational practisers including teacher educators.

Suggestions for Further Research

1) The present study was delimited to solving problems from a single area in Physics viz., Mechanics. Future researchers can investigate the effectiveness of Metacognitive Strategies on Problem Solving Skills in other areas of Physics like, Optics, Electrodynamics, Nuclear physics etc.

2) Other science disciplines like Chemistry and Biology also give importance to problem solving. Therefore, future researchers can investigate the effect of Metacognitive Strategies in Problem Solving Skills in those scientific domains.

3) Attempts to develop problem solving ability in engineering and other undergraduate students are contemporary. Future researchers can explore the possibilities of Metacognitive Strategy Instruction among those students.

4) It is observed in the present study that Peer Interacting Metacognitive Strategy Instruction have a small but significant effect over Metacognitive Strategy Instruction in transferring problem solving skills to new areas. A further detailed qualitative study employing think-aloud protocols to understand how peer interaction allows transfer of problem solving skills is required and suggested.

5) The effect of each of the component skills in problem solving viz., Representing the problem, Planning the solution, Implementing the plan and Evaluating the solution was not rigorously tested to make valid suggestions regarding each. Therefore such a study that examines in detail the effect each of these components is worth.

6) The present study employed teacher prepared concept maps for presenting knowledge domain in the first phase of Metacognitive Instruction. Construction of concept maps by students themselves may facilitate more meaningful learning. Hence, the effect of the same Metacognitive Strategy Instruction with such an alteration on problem solving skills can be investigated.

7) The extend to which present teacher education curricula equips teachers to facilitate problem solving through Metacognitive and other strategies they can employ in instruction need further verification.

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APPENDICES

Appendix A1

Test of Problem Solving Ability in Physics (Draft)

There are 42 Problems in this test. Each correct solution carries one mark. You can take 2 hours to attempt all the questions. The blank paper given can be used to work out the problems. Fill your details in the answer sheet and tick in the column for A, B, C or D against each question number. Please do not mark or write in the question paper.

1. The velocity of light in vacuum is 3×10^8 m/s. Calculate the time taken by it to travel a distance of 6×10^{14} m.
   a) 6×10^6 s b) 3×10^{14} s c) 18×10^{22} s d) 2×10^6 s
2. An electron moves with a velocity of 2×10^6 m/s. What is the distance travelled by it in 4 s?
   a) 6×10^6 m b)3×10^{14} m c) 8×10^6 m d) 2×10^6 m
3. The engine of an electric train passes a stationary car with a velocity of 6 m/s. It takes 10 s to the tail end of the train to pass the same car by which time its velocity is 9 m/s. Calculate the acceleration of the train.
   a) 0.2 m/s^2 b) 0.3 m/s^2 c) 0.1 m/s^2 d) 0.6 m/s^2
4. An electron travelling with a speed of 5×10^3 m/s pass through an electric field with an acceleration of 10^{12} m/s^2. How long will it take the electron to double its speed?
   a) 5×10^{-9} s b) 10×10^{-9} s c) 5×10^3 s d)10^{12} s
5. The velocity of a body moving with a uniform acceleration of 2 m/s^2 is 10 m/s. What is its velocity after an interval of 4 s?
   a) 18 m/s b) 0 m/s c) 20 m/s d) 10 m/s
6. A motor car moving with a uniform velocity of 20 m/s comes to stop on the application of brakes, after travelling a distance of 10 m. What is its acceleration?
   a) -10 m/s^2 b) -20 m/s^2 c) 10 m/s^2 d) 20 m/s^2
7. A projectile is fired with a horizontal velocity of 330 m/s from the top of a cliff 80 m high. How long will it take to strike the level ground at the base of the cliff?
   a) 2 s b) 3 s c) 4 s d) 5 s
8. An aircraft 500 m above ground is flying with a horizontal velocity 15 m/s. It drops a bomb. How long will it take the bomb to reach the ground?
   a) 15 s b) 5 s c) 20 s d) 10 s
9. A ball is thrown upward. After it has left the hand, its acceleration
   a) Remains constant b) increases c) decreases d) is zero
10. A stone is dropped from the top of a building. After it has left the hand, its acceleration
    a) Remains constant b) increases c) decreases d) is zero
11. A body of mass 12 kg is moving with an acceleration of 50 m/s^2. Calculate the force acting on it.
    a) 50 N b) 600N c) 150 N d) 200N
12. A ship of mass 3×10^7 kg initially at rest is pulled by a force of 6×10^4 N. Calculate the acceleration attained by the ship.
    a) 2×10^4 m/s^2 b) 2×10^3 m/s^2 c) 2×10^{-3} m/s^2 d) 18×10^{11} m/s^2

13. A train 100 m long is moving with a speed of 60 km/h. In what time shall it cross a bridge 1 km long?
    a) 60 s b) 66 s c) 30 s d) 1/60 hours.
14. A person weighting 80 km stands on a weighting machine in an elevator. In which of the following situations does the machine shows more than his actual weight?
    a) The elevator moves up with an acceleration of 10 m/s^2
    b) The elevator moves down with an acceleration of 10 m/s^2
    c) The elevator moves up with a uniform speed of 5 m/s
    d) The elevator moves down the rope nearly freely under gravity
15. A man travels in his car from home to office at 40 m/s and from office to home at 60 m/s. Calculate average speed and average velocity of that person.
    a) Average speed = 50 m/s
       Average velocity = 10 m/s
    b) Average speed = 50 m/s
       Average velocity = 0 m/s
    c) Average speed = 100 m/s
       Average velocity = 20 m/s
    d) Average speed = 20 m/s
       Average velocity = 0 m/s
16. A hunter has a machine gun that can fire 50 g bullets with a velocity of 800 m/s. A 40 kg tiger springs at him with a velocity of 10 m/s. How many bullets must the hunter fire in to the tiger in order to stop him in his track?
    a) 10 bullets b) 20 bullets c) 30 bullets d) 5 bullets
17. A car moving along a straight road with a speed of 72 km/h stops with in a distance of 200m. How long does it take the car to stop?
    a) 10 s b) 20 s c) 30 s d) 40 s
18. A stone is thrown vertically upwards with an initial velocity of 10 m/s. Find the time taken by the stone to reach back the point of projection.
    a) 1 s b) 2 s c) 3 s d) 4 s
19. A train 100 m long is moving with a speed of 60 km/h. In what time shall it cross a bridge 1.5 km long?
    a) 25 s b) 90 s c) 96 s d) 16 s
20. On a long horizontally moving belt, a child runs with a speed of 8 km/h towards his mother on the ground 500 m away. The belt is moving towards the mother with a speed of 4 km/h. In what time will the child reach his mother?
    a) 2 min b) 2 min 10 sec c) 2 min 30 sec d) 2 min 50 sec

21. Wooden body is placed on a rough plane having coefficient of friction unity. At what angle of inclination will the body just begin to slide?
    a) 30^0 b) 45^0 c) 60^0 d) 90^0
22. A boy can throw up a ball to a maximum height of 10 m. To what distance he can throw the same ball on a ground.
    a) 20 m b) 10 m c) 5 m d) 40 m
23. A force of 20N is applied on a hockey ball at an angle 30^0 with the X-axis. What is the vertical component of force?
    a) 20N b) 10N c) 5N d) 40N
24. A boy revolves a stone on a string 10 cm long steadily, completing 10 revolutions in 10 seconds. What is the angular speed of the stone?
    a) 3.14 rad/s b) 6.28 rad/s c) 1.57 rad/s d) 0.65 rad/s

25. A projectile is fired with a horizontal velocity of 330 m/s from the top of a cliff 8000 m high. How long will it take to strike the level ground at the base of the cliff?
    a) 20 s b) 10 s c) 5 s d) 40 s
26. A helicopter 500 m high is flying in horizontal direction at a speed of 144 km/h. It drops a food packet. How far should a boy just below the helicopter run to get the food packet?
    a) 900 m b) 200 m c) 400 m d) 700 m
27. An aeroplane is flying in a horizontal direction with a velocity of 360 km/h at a height of 1960 m. How far from a given target, should it release a bomb to hit the target?
    a) 500 m b) 1000 m c) 1400 m d) 2000 m
28. A monkey jumps from the branch of a tree 20 m high from the ground with a horizontal velocity of 40 m/s. How long will it stay in air?
    a) 10 s b) 5 s c) 4 s d) 2 s
29. An insect trapped in a circular groove of radius 12 cm moves along the groove steadily and completes 7 revolutions in 100 s. What is the angular speed of the insect?
    a) 5.3 rad/s b) 6.2 rad/s c) 0.53 rad/s d) 0.44 rad/s
30. A kangaroo can jump to a maximum height of 5 m. To what maximum distance can it jump on ground?
    a) 5 m b) 2.5 m c) 10 m d) $5/2^{1/2}$ m
31. A train moves towards north with a speed of 100 km/h. A monkey runs on the train towards south with a speed of 8 km/h. What is the relative velocity of the monkey with respect to an observer on the platform?
    a) 108 km/h southwards c) 92 km/h northwards
    b) 92 km/h southwards d) 108 km/h northwards
32. A body placed on a rough inclined plane just begin to slide when the angle of inclination becomes 30^0. Calculate the coefficient of friction.
    a) $1/2^{1/2}$ b) $1/ 3^{1/2}$ c) $1/15^{1/2}$ d) $1/10^{1/2}$
33. A boy is playing with a ball in a train moving with a speed of 100 km/h. If he throws up the ball with a speed of 10 m/s. How long will the ball stay in air before reaching his hands?
    a) 4 s b) 3 s c) 2 s d) 1 s
34. A monkey of mass 40 kg climbs up a rope that can withstand a maximum tension of 600N. In which of the following cases will the rope break? The monkey
    a) Climbs up with an acceleration of 6 m/s^2
    b) Climbs down with an acceleration of 4 m/s^2
    c) Climbs up with a uniform speed of 5 m/s
    d) It falls down the rope freely under gravity.
35. An aeroplane lands with a horizontal velocity of 144 km/h and comes to stop within a distance 400 m on ground. How long does it take the aeroplane to stop?
    a) 40 s b) 30 s c) 20 s d) 10 s
36. A gun weighing 10 kg fires a bullet of 30 g with a velocity of 330 m/s. With what velocity does the gun recoil?
    a) 1 m/s b) 2 m/s c) 3 m/s d) 4 m/s
37. A person drives to the fish market at a speed of 50 km/h and returns home at a speed of 70 km/h. What is the average speed and average velocity of that person?
    a) Average speed = 60 km/h
       Average velocity = 20 km/h
    c) Average speed = 20 km/h
       Average velocity = 0 km/h

b) Average speed = 20 km/h
Average velocity = 60 km/h

d) Average speed = 60 km/h
Average velocity = 0 km/h

38. A body of mass 5 kg is at rest on a plane inclined at 30^0 with the horizontal. What is the component of force along the plane?
a) 25N b) $25\times3^{1/2}$ c) 50N d) $50\times3^{1/2}$

39. A block of wood is kept on the floor of a stationary elevator. The elevator begins to descend with an acceleration of 12 m/s^2. If g=10 m/s^2, the displacement of the block during the first 0.2 second after the start is
a) 0.02 m b) 0.1 m c) 0.2 m d) 0.4 m

40. A ball is projected with a velocity of 10 m/s at an angle of 600 with the horizontal. Its velocity at the highest point is
a) 9 m/s b) 7 m/s c) 5 m/s d) 18.7 m/s

41. A projectile thrown at an angle of 45^o falls at a distance of 30 m away from the projection. Its vertical displacement is
a) 0 m b) 15 m c) 6 m d) 7 m

42. A hydrogen balloon moves up with an acceleration of 20 m/s^2. If g=10 m/s^2, the vertical displacement of the balloon after 5 seconds is
a) 0 m b) 125 m c) 250 m d) 25 m

Appendix A2

Answer key – Test of Problem Solving Ability in Physics (Draft)

Question No.	Answer key
1	d
2	c
3	b
4	a
5	a
6	b
7	c
8	d
9	a
10	a
11	d
12	c
13	b
14	a
15	b
16	a
17	b
18	b
19	c
20	c
21	b

Question No.	Answer key
22	a
23	b
24	b
25	d
26	c
27	c
28	d
29	d
30	c
31	c
32	b
33	c
34	a
35	c
36	a
37	d
38	d
39	c
40	c
41	b
42	c

Appendix A3

ITEM WISE INDICES OF DIFFICULTY AND DISCRIMINATION FOR THE TESTS (FORMS A & B) OF PROBLEM SOLVING ABILITY IN PHYSICS

Item Number	Difficulty Index	Discriminating Power	Item Number (Final Test)
1*	0.80	0.33	A1
2*	0.85	0.30	B1
3*	0.68	0.41	A2
4*	0.40	0.40	B2
5*	0.60	0.60	A3
6*	0.50	0.50	B3
7*	0.40	0.40	A4
8*	0.40	0.70	B4
9	0.23	0.20	--
10*	0.40	0.40	B5
11*	0.20	0.30	A5
12	0.11	0.21	--
13*	0.30	0.60	A6
14*	0.60	0.30	B6
15*	0.40	0.30	A7
16*	0.30	0.40	B7
17*	0.40	0.30	A8
18*	0.60	0.60	B8
19*	0.50	0.80	A9
20*	0.30	0.50	B9
21*	0.50	0.40	A10
22*	0.30	0.40	B10
23*	0.60	0.70	A11
24*	0.50	0.70	B11
25*	0.30	0.50	A12
26*	0.40	0.70	B12
27*	0.20	0.30	A13
28*	0.40	0.40	B13
29	0.20	0.10	--
30	0.40	0.40	--
31*	0.40	0.30	A14
32*	0.30	0.30	B14
33	0.10	0.21	--
34*	0.70	0.40	B15
35*	0.30	0.30	A15
36	0.40	0.20	--
37	0.30	0.11	--
38	0.20	0.21	--
39	0.11	0.11	--
40	0.20	0.20	--
41	0.20	0.13	--
42	0.20	0.10	--

*indicate item in the final test.

Appendix A4

TEST OF PREVIOUS PROBLEM SOLVING ABILITY IN PHYSICS

(FORM A, PRE-TEST)

There are 15 Problems in this test. Each correct solution carries one mark. You can take 45 minutes to attempt all the questions. The blank paper given can be used to work out the problems. Fill your details in the answer sheet and tick in the column for A, B, C or D against each question number. Please do not mark or write in the question paper.

1. The velocity of light in vacuum is 3×10^8 m/s. Calculate the time taken by it to travel a distance of 6×10^{14} m.
   b) 6×10^6 s b) 3×10^{14} s c) 18×10^{22} s d) 2×10^6 s
2. The engine of an electric train passes a stationary car with a velocity of 6 m/s. It takes 10 s to the tail end of the train to pass the same car by which time its velocity is 9 m/s. Calculate the acceleration of the train.
   a) 0.2 m/s^2 b) 0.3 m/s^2 c) 0.1 m/s^2 d) 0.6 m/s^2
3. The velocity of a body moving with a uniform acceleration of 2 m/s^2 is 10 m/s. What is its velocity after an interval of 4 s?
   a) 18 m/s b) 0 m/s c) 20 m/s d) 10 m/s
4. A projectile is fired with a horizontal velocity of 330 m/s from the top of a cliff 80 m high. How long will it take to strike the level ground at the base of the cliff?
   b) 2 s b) 3 s c) 4 s d) 5 s
5. A body of mass 12 kg is moving with an acceleration of 50 m/s^2. Calculate the force acting on it.
   b) 50 N b) 600N c) 150 N d) 200N
6. A train 100 m long is moving with a speed of 60 km/h. In what time shall it cross a bridge 1 km long?
   b) 60 s b) 66 s c) 30 s d) 1/60 hours.
7. A man travels in his car from home to office at 40 m/s and from office to home at 60 m/s. Calculate average speed and average velocity of that person.
   c) Average speed = 50 m/s
      Average velocity = 10 m/s
   c) Average speed = 100 m/s
      Average velocity = 20 m/s
   d) Average speed = 50 m/s
      Average velocity = 0 m/s
   d) Average speed = 20 m/s
      Average velocity = 0 m/s
8. A car moving along a straight road with a speed of 72 km/h stops with in a distance of 200m. How long does it take the car to stop?
   b) 10 s b) 20 s c) 30 s d) 40 s
9. A train 100 m long is moving with a speed of 60 km/h. In what time shall it cross a bridge 1.5 km long?
   b) 25 s b) 90 s c) 96 s d) 16 s
10. Wooden body is placed on a rough plane having coefficient of friction unity. At what angle of inclination will the body just begin to slide?
    b) 30^0 b) 45^0 c) 60^0 d) 90^0

11. A force of 20N is applied on a hockey ball at an angle 30^0 with the X-axis. What is the vertical component of force?
    b) 20N b) 10N c) 5N d) 40N
12. A projectile is fired with a horizontal velocity of 330 m/s from the top of a cliff 8000 m high. How long will it take to strike the level ground at the base of the cliff?
    b) 20 s b) 10 s c) 5 s d) 40 s
13. An aeroplane is flying in a horizontal direction with a velocity of 360 km/h at a height of 1960 m. How far from a given target, should it release a bomb to hit the target?
    b) 500 m b) 1000 m c) 1500 m d) 2000 m
14. A train moves towards north with a speed of 100 km/h. A monkey runs on the train towards south with a speed of 8 km/h. What is the relative velocity of the monkey with respect to an observer on the platform?
    c) 108 km/h southwards c) 92 km/h northwards
    d) 92 km/h southwards d) 108 km/h northwards
15. An aeroplane lands with a horizontal velocity of 144 km/h and comes to stop within a distance 400 m on ground. How long does it take the aeroplane to stop?
    b) 40 s b) 30 s c) 20 s d) 10 s

Appendix A5

TEST OF ANALOGICAL PROBLEM SOLVING ABILITY IN PHYSICS (FORM B, POST-TEST)

There are 15 Problems in this test. Each correct solution carries one mark. You can take 45 minutes to attempt all the questions. The blank paper given can be used to work out the problems. Fill your details in the answer sheet and tick in the column for A, B, C or D against each question number. Please do not mark or write in the question paper.

1. An electron moves with a velocity of 2×10^6 m/s. What is the distance travelled by it in 4 s?
   b) 6×10^6 m b)3×10^{14} m c) 8×10^6 m d) 2×10^6 m
2. An electron travelling with a speed of 5×10^3 m/s pass through an electric field with an acceleration of 10^{12} m/s^2. How long will it take the electron to double its speed?
   b) 5×10^{-9} s b) 10×10^{-9} s c) 5×10^3 s d)10^{12} s
3. A motor car moving with a uniform velocity of 20 m/s comes to stop on the application of brakes, after travelling a distance of 10 m. What is its acceleration?
   b) -10 m/s^2 b) -20 m/s^2 c) 10 m/s^2 d) 20 m/s^2
4. An aircraft 500 m above ground is flying with a horizontal velocity 15 m/s. It drops a bomb. How long will it take the bomb to reach the ground?
   b) 15 s b) 5 s c) 20 s d) 10 s
5. A stone is dropped from the top of a building. After it has left the hand, its acceleration
   b) Remains constant b) increases c) decreases d) is zero
6. A person weighting 80 km stands on a weighting machine in an elevator. In which of the following situations does the machine shows more than his actual weight?
   e) The elevator moves up with an acceleration of 10 m/s^2
   f) The elevator moves down with an acceleration of 10 m/s^2
   g) The elevator moves up with a uniform speed of 5 m/s
   h) The elevator moves down the rope nearly freely under gravity
7. A hunter has a machine gun that can fire 50 g bullets with a velocity of 800 m/s. A 40 kg tiger springs at him with a velocity of 10 m/s. How many bullets must the hunter fire in to the tiger in order to stop him in his track?
   b) 10 bullets b) 20 bullets c) 30 bullets d) 5 bullets
8. A stone is thrown vertically upwards with an initial velocity of 10 m/s. Find the time taken by the stone to reach back the point of projection.
   b) 1 s b) 2 s c) 3 s d) 4 s
9. On a long horizontally moving belt, a child runs with a speed of 8 km/h towards his mother on the ground 500 m away. The belt is moving towards the mother with a speed of 4 km/h. In what time will the child reach his mother?
   a) 2 min b) 2 min 10 sec c) 2 min 30 sec d) 2 min 50 sec
10. A boy can throw up a ball to a maximum height of 10 m. To what distance he can throw the same ball on a ground.

b) 20 m   b) 10 m   c) 5 m   d) 40 m

11. A boy revolves a stone on a string 10 cm long steadily, completing 10 revolutions in 10 seconds. What is the angular speed of the stone?

    b) 3.14 rad/s   b) 6.28 rad/s   c) 1.57 rad/s   d) 0.65 rad/s

12. A helicopter 500 m high is flying in horizontal direction at a speed of 144 km/h. It drops a food packet. How far should a boy just below the helicopter run to get the food packet?

    b) 900 m   b) 200 m   c) 400 m   d) 700 m

13. A monkey jumps from the branch of a tree 20 m high from the ground with a horizontal velocity of 40 m/s. How long will it stay in air?

    b) 10 s   b) 5 s   c) 4 s   d) 2 s

14. A monkey of mass 40 kg climbs up a rope that can withstand a maximum tension of 600N. In which of the following cases will the rope break? The monkey

    e) Climbs up with an acceleration of 6 m/s^2
    f) Climbs down with an acceleration of 4 m/s^2
    g) Climbs up with a uniform speed of 5 m/s
    h) It falls down the rope freely under gravity.

15. A body placed on a rough inclined plane just begin to slide when the angle of inclination becomes 30^0. Calculate the coefficient of friction.

    b) $1/2^{1/2}$ b) $1/ 3^{1/2}$ c) $1/15^{1/2}$ d) $1/10^{1/2}$

Appendix B1

TEST OF PROBLEM SOLVING SKILLS IN PHYSICS (DRAFT)

There are 20 Problems in this test. Each correct solution carries one mark. You can take 1 hour to attempt all the questions. The blank paper given can be used to work out the problems. Fill your details in the answer sheet and tick in the column for A, B, C or D against each question number. Please do not mark or write in the question paper.

1. A man carries a body of mass 2 Kg to the top of a building 20 m high. What is the work done by the man? Take g=10 m/s^2
   a) 200 J b) 400 J c) 2000 J d) 40 J
2. What is the power of an elevator that can carry a mass of 500 kg over a building 10 m high in one minute?
   a) 83 W b) 38 W c) 25 W d) 15 W
3. Find the torque due to a force of 2N applied at 2.5 m perpendicular from the point of application of force.
   a) 5 Nm b) 2.5 Nm c) 2 Nm d) 1.5 Nm
4. When the distance between the two masses is doubled, the gravitational force between the masses will become
   a) ¼ b) ½ c) double d) 4 times
5. The acceleration due to gravity ________ when we go below the earth surface.
   a) Increases b) decreases c)remains same d) becomes zero
6. A force of 100N is applied on a wire of cross-sectional area 4×10^{-5} m^2. What is the stress experienced by the wire?
   a) 104×10^{-5} N/m^2 b) 96×10^{5} N/m^2 c) 25×10^{5} N/m^2 d) 400×10^{-5} N/m^2
7. At a depth of 1000 m in an ocean what is the gauge pressure? Density of sea water is 1.03×10^{3} kg/m^3. Take g=10 m/s^2.
   a) 10.3×10^{3} Pa b) 5.2×10^{4} Pa c) 5.2×10^{5} Pa d) 10.3×10^{6} Pa
8. A cylindrical tube of spray has an area of cross section of 8 cm^2. If the liquid flows inside the tube with a speed of 2 m/s. What will be the speed of the liquid through the other end that has a cross-sectional area of 1 cm^2.
   a) 4 m/s b) 6 m/s c) 10 m/s d) 16 m/s
9. A particle moves along a straight line. What happens to the kinetic energy of the particle if its velocity changes from -4 m/s to -3 m/s?
   a) Increases b) decreases c) remains samed) becomes zero
10. A bullet of mass 20 g is found to pass two points 40 m apart in a time interval of 4 seconds. If it moves with a constant speed, what is the kinetic energy of the bullet?
    a) 0.562 J b) 1J c) 0.1 J d) 2J
11. A wheel 2 m in radius is moving with a speed of 10 m/s. Calculate its angular speed.
    a) 16.67 rad/s b) 2 rad/s c) 5 rad/s d)10 rad/s

12. There are two spheres A and B of equal masses. Sphere A roll down a smooth inclined plane of height h. Sphere B falls freely through height h. Which ball does more work?
    a) Ball A b) Ball B
    c) Both balls does not do any work d) work done by both balls are the same.
13. A 50 Kg man stands 1 m away from a 20 Kg boy. Calculate the force of gravitational attraction between them. Given $G=6.66\times10^{-11}\ Nm^2/Kg^2$
    a) 50×10^{-11} N b) 6.66×10^{-11}N c) 6.66×10^{-8}N d)20×10^{-11}N
14. Calculate the force required to increase the length of a steel wire of cross-sectional area $10^{-6}\ m^2$ by 50percent. Given $Y=2\times10^{11}N/m^2$.
    a) 10^{10} N b) 10^5 N c) 2×10^{10} N d) 2×10^5 N
15. Water is filled in a flask up to a height of 20 cm. The bottom of the flask is circular and has an area of 1 m^2. If the atmospheric pressure is 1.01×10^5 Pa, then what force is exerted by water at the bottom? (Take $g=10\ m/s^2$ and density of water=$1000kg/m^3$).
    a) 1.03×10^5 N b) 3.01×10^5 N c) 1.01×10^5 N d) 2.01×10^5 N
16. A tank containing water has an orifice 20 m below the surface of water in the tank. If there is no wastage of energy, find the speed of discharge.
    a) 20 m/s b) 40 m/s c) 10 m/s d) 30 m/s
17. A flask contains glycerine and the other one contains water. Both are stirred rapidly and kept on the table. In which flask will, the liquid comes to rest earlier.
    a) Water b) glycerine c) both comes to rest together d) cannot predict
18. What is the youngs modulus of elasticity for a perfectly rigid body?
    a) Infinity b)zero c) one d) minus one
19. A fluid flows steadily through a cylindrical pipe, which has radius 2R at point A and radius R at point B farther along the flow direction. If the velocity at point A is V, the velocity at point B will be
    a) 2V b) V c) V/2 d)4V
20. A cord is wound around the circumference of a wheel of diameter 0.3 m. A 0.5 Kg mass is attached at the end of the cord and it is allowed to fall from rest. What is the torque produced?
    a) 0.7 Nm b) 1.25×4 Nm c) 4.9/0.15 Nm d) 1.25×9.8 Nm

Appendix B2

Answer Key – Test of Problem Solving Skills in Physics (Draft)

Question No.	Answer key
1	b
2	a
3	a
4	a
5	b
6	c
7	d
8	d
9	b
10	b
11	c
12	d
13	c
14	b
15	a
16	a
17	b
18	c
19	a
20	d

Appendix B3

ITEM WISE INDICES OF DIFFICULTY AND DISCRIMINATION FOR THE TEST OF PROBLEM SOLVING SKILLS IN PHYSICS

Item Number	Discriminating Power	Difficulty index	Item Number (Final Test)
1*	0.41	0.72	1
2	0.15	0.11	--
3*	0.44	0.74	2
4*	0.41	0.50	3
5*	0.59	0.67	4
6*	0.67	0.52	5
7*	0.67	0.52	6
8*	0.59	0.33	7
9*	0.37	0.44	8
10	0.22	0.37	--
11*	0.74	0.55	9
12	0.26	0.13	--
13*	0.70	0.57	10
14*	0.30	0.30	11
15	0.26	0.20	--
16*	0.44	0.30	12
17*	0.52	0.33	13
18*	0.37	0.30	14
19*	0.33	0.17	15
20	0.19	0.09	--

*indicate items in the final form of the test.

Appendix B4

TEST OF PROBLEM SOLVING SKILLS IN PHYSICS

There are 15 Problems in this test. Each correct solution carries one mark. You can take 45 minutes to attempt all the questions. The blank paper given can be used to work out the problems. Fill your details in the answer sheet and tick in the column for A, B, C or D against each question number. Please do not mark or write in the question paper.

1. A man carries a body of mass 2 kg to the top of a building 20 m high. What is the work done by the man? Take g=10 m/s^2
   a) 200 J b) 400 J c) 2000 J d) 40 J
2. Find the torque due to a force of 2N applied at 2.5 m perpendicular from the point of application of force.
   a) 5 Nm b) 2.5 Nm c) 2 Nm d) 1.5 Nm
3. When the distance between the two masses is doubled, the gravitational force between the masses will become
   a) ¼ b) ½ c) double d) 4 times
4. The acceleration due to gravity ________ when we go below the earth surface.
   a) Increases b) decreases c)remains same d) becomes zero
5. A force of 100N is applied on a wire of cross-sectional area 4×10^{-5} m^2. What is the stress experienced by the wire?
   a) 104×10^{-5} N/m^2 b) 96×10^{5} N/m^2 c) 25×10^{5} N/m^2 d) 400×10^{-5} N/m^2
6. At a depth of 1000 m in an ocean what is the gauge pressure? Density of sea water is 1.03×10^{3} kg/m^3. Take g=10 m/s^2.
   a) 10.3×10^{3} Pa b) 5.2×10^{4} Pa c) 5.2×10^{5} Pa d) 10.3×10^{6} Pa
7. A cylindrical tube of spray has an area of cross section of 8 cm^2. If the liquid flows inside the tube with a speed of 2 m/s. What will be the speed of the liquid through the other end that has a cross-sectional area of 1 cm^2.
   a) 4 m/s b) 6 m/s c) 10 m/s d) 16 m/s
8. A particle moves along a straight line. What happens to the kinetic energy of the particle if its velocity changes from -4 m/s to -3 m/s?
   a) Increases b) decreases c) remains same d) becomes zero
9. A wheel 2 m in radius is moving with a speed of 10 m/s. Calculate its angular speed.
   a) 16.67 rad/s b) 2 rad/s c) 5 rad/s d)10 rad/s
10. A 50 Kg man stands 1 m away from a 20 Kg boy. Calculate the force of gravitational attraction between them. Given $G=6.66\times10^{-11}$ Nm^2/Kg^2
    a) 50×10^{-11} N b) 6.66×10^{-11}N c) 6.66×10^{-8}N d)20×10^{-11}N
11. Calculate the force required to increase the length of a steel wire of cross-sectional area 10^{-6} m^2 by 50%. Given $Y=2\times10^{11}$N/m^2.
    a) 10^{10} N b) 10^{5} N c) 2×10^{10} N d) 2×10^{5} N

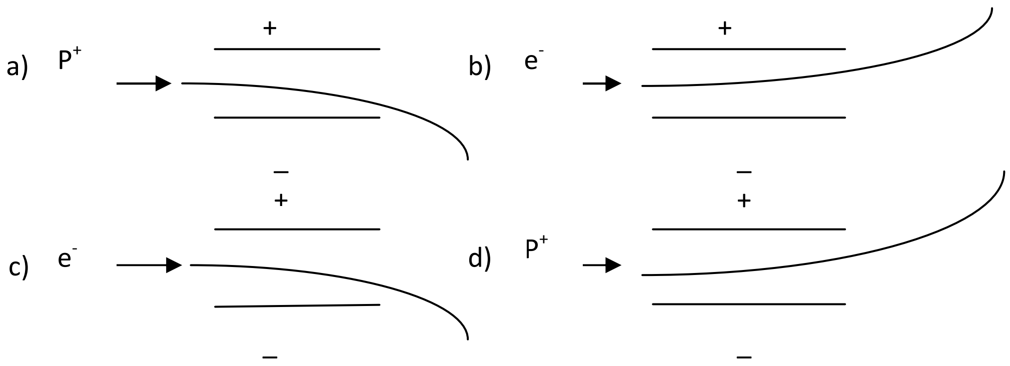
12. A tank containing water has an orifice 20 m below the surface of water in the tank. If there is no wastage of energy, find the speed of discharge.
    a) 20 m/s b) 40 m/s c) 10 m/s d) 30 m/s
13. A flask contains glycerine and the other one contains water. Both are stirred rapidly and kept on the table. In which flask will, the liquid comes to rest earlier.
    a) water b) glycerine c) both comes to rest together d) cannot predict
14. What is the youngs modulus of elasticity for a perfectly rigid body?
    a) infinity b)zero c) one d) minus one
15. A fluid flows steadily through a cylindrical pipe, which has radius 2R at point A and radius R at point B farther along the flow direction. If the velocity at point A is V, the velocity at point B will be
    a) 2V b) V c) V/2 d)4V

Appendix C1

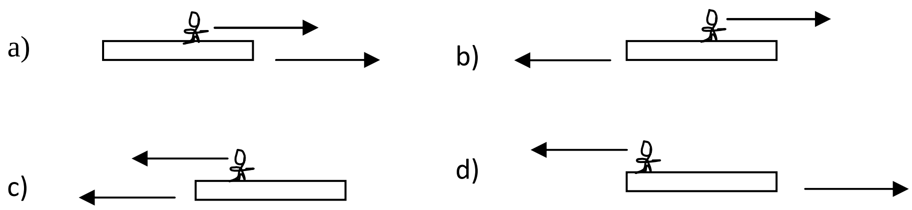
TEST ON COMPONENT SKILLS IN PROBLEM SOLVING

> There are 20 questions in this test. Each correct answer carries one mark. You can take one hour to attempt all the questions. The blank paper given can be used to work out the problems. Fill your details in the answer sheet and tick in the column for A, B, C or D against each question number. Please do not mark or write in the question paper.

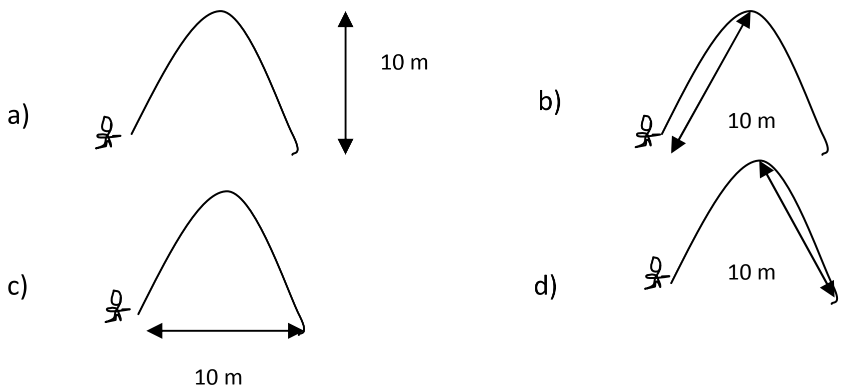
1. Which among these represent the motion of an electron through an electric field?



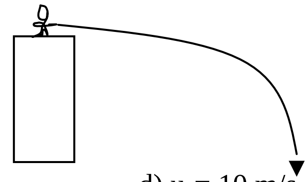
2. A train is moving with a speed of 100 km/h northwards. A monkey runs on the train with a speed of 10 km/h southwards. Which of these following figures represent this situation?



3. A boy can throw up a ball to a maximum height of 10 m. This is represented by

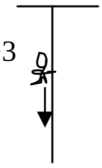
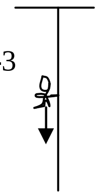
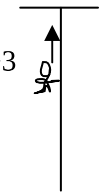
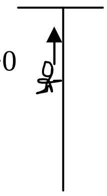


4. In the given figure, can you guess the initial velocity of the stone in vertical direction?



a) u_v=15 m/s b) u_v= 10 m/s c) u_v=0 m/s d) u_v= 10 m/s

5. A monkey climbs up a rope with an acceleration 3 m/s^2. Which of the following represents the motion of monkey?

a) a=g+3  b) a=g-3  c) a=g+3  d) a=g+0 

6. A proton travelling with a speed of 2×10^3 m/s pass through an electric felid with an acceleration of 10^6 m/s^2. How long will it take the proton to get 4 times its initial speed? Which of the following equations will you use?

a) v=u+at b) $s=ut+{}^1/_2at^2$ c) $v^2=u^2+2as$ d) a=dv/dt

7. A bus moving with a uniform velocity of 40 m/s comes to stop on the application of breaks, after travelling a distance of 20 m. Which of the following equations will you use to find its acceleration?

a) v=u+at b) $s=ut+{}^1/_2at^2$ c) $v^2=u^2+2as$ d) a=dv/dt

8. Which among the following expressions represents the kilogram weight of an accelerating body?

a) ma b) ma/g c) mg/a d) mg

9. If a hunter fires n bullets of mass m at velocity v to stop a tiger of mass M jumping with a velocity V. Which equation will you use to find the number of required bullets?

a) n= mv/MV b) n=Mm/Vv c)n=vV/mM d) n=MV/mv

10. When a stone is thrown upwards,

a) time for upward motion < time for downward motion
b) time for upward motion > time for downward motion
c) time for upward motion = 2 times time for downward motion
d) time for upward motion = time for downward motion

11. Solve this $\dfrac{3\times10^5\times6\times10^{-2}}{9\times10^7}$

a) 2×10 b) 2×10 c) 3×10^{12} d) 2×10^{12}

12. If $v^2=u^2+2as$ then

a) $S=v^2-u^2-2a$ b) $S=\dfrac{v^2-u^2}{2a}$ c) $S=\dfrac{2a}{v^2-u^2}$ d) $S=u^2+2a-v^2$

13. What is the angle of projection for maximum height?

a) 45^0 b)90^0 c) 30^0 d) 60^0

14. If tan θ= 0. Then θ=______

a) 45^0 b) 90^0 c) 30^0 d)0^0

15. Given $S= ut + {}^{1}/_{2}at^2$. If S=500m, u=12km/h and a=0, find t.

a) 500s b) 41s c) 2min 30s d) 1min 20s

16. A bus moving with a uniform velocity comes to stop on the application of brakes. The acceleration of the bus will be

a) Positive b) negative c) zero d) cannot be predicted

17. When a stone is thrown upwards, its acceleration

a) Increases b) decreases c) remains constant d) is zero

18. When a stone falls down its velocity

a) Increases b) decreases c) remains constant d) is zero

19. A boy revolves a stone on a string completing 10 revolutions in 10 seconds. Is it possible to find the angular speed of the stone from this information?

a) No, because velocity of the stone is not given
b) No, because radius of the string is not given
c) No, because length of the string is not given
d) Yes, angular speed can be determined

20. A cyclist makes circular motions on a ring completing 10 revolutions in 10 seconds. Is it possible to find the linear velocity of the cyclist from this information?

a) No, because height of the cyclist is not given
b) No, because radius of the ring is not given
c) No, because angular speed of the cyclist is not given
d) Yes, linear velocity can be determined

Appendix C2

Answer key – Test on Component Skills in Problem Solving

Question No.	Answer key
1	b
2	d
3	a
4	a
5	c
6	a
7	c
8	d
9	d
10	d
11	b
12	b
13	b
14	d
15	c
16	b
17	c
18	a
19	d
20	b

Appendix D

METACOGNITIVE STRATEGY INSTRUCTION MODULE

Introduction

Metacognitive Strategy Instruction Module is developed to enhance Problem Solving Skills in Physics by explicit instruction of using metacognitive strategies while solving physics problems. This module can be used to instruct the students in a class room, where the students work either individually or in small groups.

This module consists of 30 lessons. Out of these thirty lessons ten lessons each are on the three units, 'Motion in a Straight Line', 'Motion in a Plane' and 'Laws of Motion'. Out of each of these ten lessons, first two lessons aim to present the knowledge domain and the rest of eight lessons focus on solving problems related to the topics dealt in the first two lessons.

The first two lessons on each unit consists of a single phase namely, Presentation of the Knowledge Domain. The rest of the eight lessons consist of three other phases. Each of these four phases is described below.

Phase 1: Presentation of Knowledge domain.

In this phase the teacher presents the concepts and the relation between them as an interconnected fabric. ie., in the form of a concept map. The concept map is developed on the black board as the teacher explains each concept (Eg: Motion in a Straight Line) and the sub concepts (Eg: Velocity) with examples from real life situations. The teacher introduces the minor concepts (Eg: Average Velocity) related to each sub concept and explains how they can be computed from various physical quantities. Meanwhile, teacher also demonstrates how each of the equations can be used to solve problems.

Phase 2: Presentation of the Problem

In this phase teacher presents a story problem where numerical values are embedded in a real life situation involving the physics concepts under discussion. Students have to estimate the unknown quantities using physics concepts and relationships.

Phase 3: Problem solving procedure.

This phase consists of four steps in which a given problem is solved.

Step 1: Surface representation

In this step, the problem situation is represented in the form of a diagram. All the given variables with their values and the unknown quantities to be determined are indicated in the diagram.

Step 2: Structure Representation

In this step teacher and students discuss the physics concepts in the problem situation. They view the problem in the frame work of physical science principles and make the assumptions necessary for the solution of the problem.

Step 3: Planning the solution

In this step, on the bases of the previous representations of the problem, teacher and pupils together decide which equations can be used to solve the problem. They also plan how to work out the problem using the equations and assumptions, through a series of steps.

Step 4: Implementing the plan

In this step teacher and students proceed according to their plan and solve the problem.

Phase 4: Metacognitive Analysis

This phase consisted of three steps which helps in verification of the solution and reflection on the strategy used.

Step 1: Error Analysis

In this step students investigate whether the equations used are consistent unit wise, whether the assumptions made are correct and whether the solution obtained is reasonable

Step 2: Monitoring the Procedure

In this step teacher makes the students reflect on the procedure followed so that the physical science principles and the strategy for solving the problem gets fixed in their mind. Teacher does that by asking a set of reflective questions

Step 3. Analogical Problem Solving

In this step teacher provides a problem similar to the one presented in phase 2 and ask students to solve it, following all the steps in phases 3 and 4.

LESSON TRANSCRIPTS

Lesson 1: Displacement and Velocity

Name of teacher	:	Shareeja Ali M C
Class	:	11
Unit	:	Motion in a Straight Line
Time	:	1 hour

Objectives: To enable students to

- Define path length and displacement
- Compute path length and displacement
- Compare and contrast path length and displacement
- Define average speed and average velocity
- To compute average speed and average velocity
- To compare and contrast average speed and average velocity
- To define instantaneous velocity
- To compute instantaneous velocity

Resources: Concept map, diagrams

Phase 1: Presentation of Knowledge domain.

(The concept map for the unit, 'Motion in a Straight Line' developed during the lesson is shown in figure.)

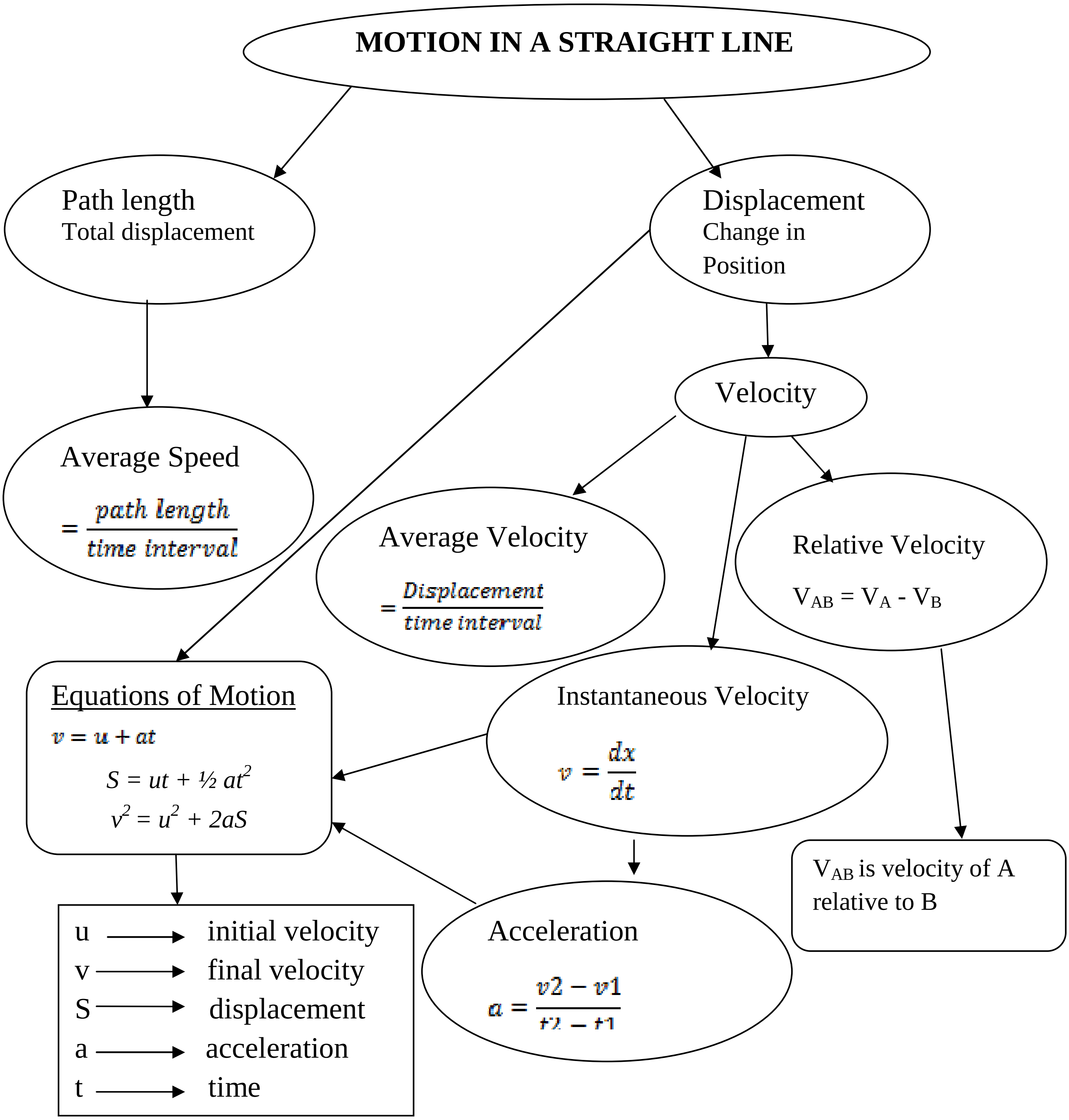


__Figure__: Concept map for the unit 'Motion in a Straight Line'

Teacher:	*Everything around us moves. Can you tell some things that you saw moving today?*
Pupil:	*Car, bus, people, ball etc.….*
Teacher:	*Today let us discuss Motion of bodies in a straight line. When a body moves in a straight line, its position changes. We can discuss two concepts related to its motion.* *Path length and Displacement* *Path length is the total distance travelled by the body and displacement is the change in position.* (Teacher counts and walks three steps) *If I cover 1 meter in one step, what is my path length now?*
Pupil:	*3 meters*
Teacher:	*Correct. What is my displacement?*
Pupil:	*3 meters*
Teacher:	*correct*
	(Teacher walks back one meter)
Teacher:	*Now what is my total path length?*
Pupil:	*4 meter*
Teacher:	*That is correct. Can you tell my total displacement?*
Pupil:	*Not sure*
Teacher:	*2 meters, because I am only 2 meters away from my original position*
	(Teacher walks back to her original position)
Teacher:	*Now what is my total path length?*
Pupil:	*6 meters*
Teacher:	*What is my displacement?*
Pupil:	*zero meters*
	(Teacher walks two steps backwards)
Teacher:	*Now what is my path length?*
Pupil:	*8 meters*
Teacher:	*What is my displacement?*
Pupil:	*2 metes*
Teacher:	*It is -2 meters, because displacement depends on direction.* *So we see that, displacement can be equal to path length, less than that, zero or even negative.*

	Now we can discuss two other quantities related to path length and displacement. They are average speed and average velocity. Path length divided by time is called average speed and displacement divided by time is called average velocity.
	(Teacher makes 6 steps forward in 2 seconds and asks)
Teacher:	*Now I moved 6 meters in 2 seconds. What is my average speed?*
Pupil:	*3 meter/second*
Teacher:	*Correct. What is my average velocity?*
Pupil:	*3 m/s*
	(Teacher walks back 6 meters in another 2 seconds)
Teacher:	*What is the average speed of total motion?*
Pupil:	*3 m/s*
Teacher:	*What is the average velocity of total motion?*
Pupil:	*0 m/s*
Teacher:	*Very good. Since displacement is zero, average velocity is zero. Most of the time what we need is instantaneous velocity and not average velocity. Often, we move with changing velocities. For example, let us take the case of a car, it moves slowly in the beginning, then fast, etc…. The speed is not a constant. In such case velocity at each instant will be different. Velocity at an instant is called instantaneous velocity.*
	Have you seen speedometer inside a car or a bus?
Pupil:	*Yes*
Teacher:	*Can you guess the type of velocity shown in a speedometer? Is it average or instantaneous?*
Pupil:	*Instantaneous*
Teacher:	*Correct it is calculated as the time derivative of position. Suppose position is given as*
	$x = 3t^2 + 2t + 4$
	What will be the velocity after 2 seconds?
Pupil:	(Workout in their note book. Teacher offers guidance to some students)
	$v = dx / dt$
	$= 3\times 2t + 2$
	$= 6t + 2$

After 2 seconds,

$$v = 6 \times 2 + 2$$
$$= 14\ m/s$$

(Teacher summarizes the concepts taught and asks questions to reinforce what students learned.)

Teacher: *What is the difference between path length and displacement?*
What is the difference between average speed and average velocity?
How can we determine instantaneous velocity?

Lesson 2: Relative Velocity and Acceleration

Name of teacher	:	Shareeja Ali M C
Class	:	11
Unit	:	Motion in a Straight Line
Time	:	1 hour

Objectives: To enable students to

- Define relative velocity
- Compute relative velocity
- Define acceleration
- Compute acceleration
- Compare displacement, velocity and acceleration
- Recall equations of motion
- Apply equations of motion in various situations.

Resources: Concept map, diagrams

Phase 1: Presentation of the knowledge domain

(Teacher refreshes the topics covered in the previous lesson while retracing the concept map already drawn)

Teacher: *Now let us discuss another type of velocity called relative velocity. This comes to play when more than one body is moving. Suppose there are two trains, A and B moving with velocities V_A and V_B. Then velocity of train A relative to train B is*

$$V_{AB} = V_A - V_B$$

Suppose train A is moving Northwards with a speed of 60m/s and train B is moving Northwards with a speed of 40m/s. What is velocity of train A relative to train B?

Pupil: (Workout in their note book. Teacher offers guidance to some students)

$$V_{AB} = V_A - V_B$$
$$= 60 - 40$$
$$= 20m/s$$

Teacher: *What will be the relative velocity if B is moving southwards?*

Pupil: (Workout in their note book. Teacher offers guidance to some students)

$$V_{AB} = V_A - V_B$$

	$= 60 + 40$
	$= 100\ m/s$
Teacher:	*Correct. But why did you take 60 + 40*
Pupil:	*Now train B is moving southwards, opposite to the direction of train A, so* $V_B = -40 m/s$
Teacher:	*Excellent.* *Now let us discuss another physical quantity related to velocity, which is acceleration. It is defined as change in velocity divided by time interval.* *What will be the acceleration of a body moving with a constant velocity?*
Pupil:	*Zero*
Teacher:	*Good* *Suppose a car stars from rest and accelerates to a velocity of 40 m/s in 5 seconds. What will be its acceleration?*
Pupil:	(Workout in their note book. Teacher offers guidance to some students) *Acceleration = Change in velocity/ time* $a = (v_2 – v_1)/t$ $= (40 – 0)/5$ $= 8\ m/s^2$
Teacher:	*Correct. Now suppose car stops in 10 seconds. What will be its acceleration?*
Pupil:	(Workout in their note book. Teacher offers guidance to some students) $a = (v_2 – v_1)/t$ $= (0 – 40)/10$ $= -4\ m/s^2$
Teacher:	*So we see that just like displacement and velocity, acceleration also can be zero, positive or negative.* *Now we can discuss three equations of motion. These equations connect five physical quantities namely, final velocity (v), initial velocity (u), acceleration (a), displacement (s) and time (t). If any three of them are known, other two can be determined using these equations.* (Teacher writes the equations on the black board) *Let us see how these equations can be used.*

	For example, when a ball is thrown from the top of a building, it reaches the ground in 5s. What is the velocity just before it touches the ground?
	What physical quantity is given in this example?
Pupil:	*time = 5s*
Teacher:	*What will be the initial velocity of the ball?*
Pupil:	*Zero*
Teacher:	*Why is it zero?*
Pupil:	*It is said that the ball starts moving. So it is at rest in the beginning.*
Teacher:	*Correct. What will be the acceleration on the ball?*
Pupil:	$9.8\ m/s^2$
Teacher:	*Why is it* $9.8\ m/s^2$*?*
Pupil:	*The ball accelerates due to gravity.*
Teacher:	*Correct. So we have time (t), initial velocity (u) and acceleration (a). Which equation can we use to find final velocity (v)?*
Pupil:	$v = u + at$
Teacher:	*Good. Substitute the quantities and find v.*
Pupil:	(Workout in their note book. Teacher offers guidance to some students) $v = 0 + 9.8 \times 5$ $= 49\ m/s$
Teacher:	*Correct. Now can you find the height of the building?*
Pupil:	*Yes. It is the distance travelled by the ball.*
Teacher:	*Which equation will you use?*
Pupil:	$S = ut + ½\ at^2$
Teacher:	*Ok. Then substitute the values in the equation and find the height (S).*
Pupil:	(Workout in their note book. Teacher offers guidance to some students) $S = 0 \times 5 + ½ \times 9.8 \times 5^2$ $= 122.5\ m$
Teacher:	*Correct. Similarly, we can use these equations in different situations. Let us now summarize what we learned today and in the last lesson.*

(Teacher completes the concept map and asks students to understand and copy that in their note books)

Lesson 3: Solving Problems Using Equations of Motion I

Name of teacher : Shareeja Ali M C
Class : 11
Topic : Motion in a Straight Line
Time : 1 hour

Objectives: To enable students to

- Draw a schematic diagram representing a given problem situation
- Identify different physical quantities given in a story problem
- Select appropriate equations to solve a problem
- Apply equations of motion to compute an unknown physical quantity

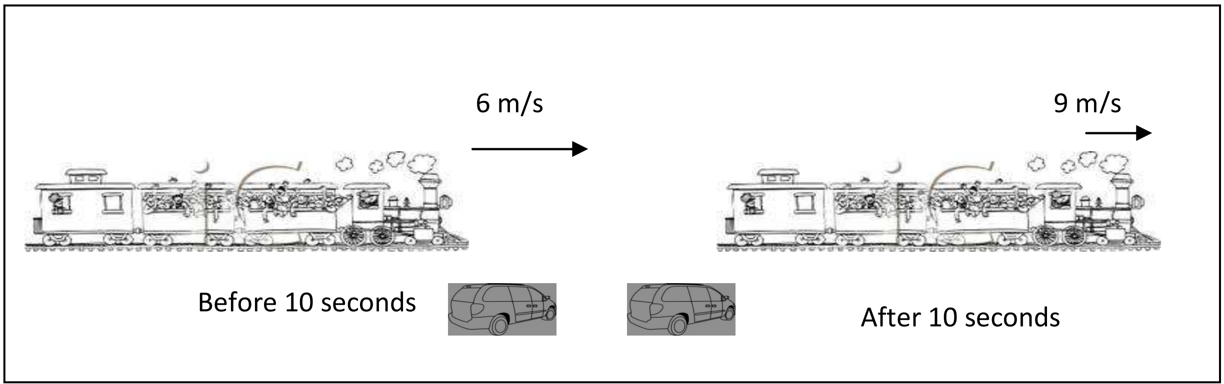
Resources: Concept map, diagrams

Phase 2: Presentation of the Problem

Teacher:	*The engine of an electric train passes a stationary car with a velocity of 6 m/s. It takes 10 seconds to the tail end of the train to pass the same car by which time its velocity is 9m/s. Calculate the acceleration of the train.*

Phase 3: Problem solving procedure.

Step 1: Surface representation



Step 2: Structure Representation

Teacher:	*Let us discuss the motion of the train. With what speed is the train approaching the car?*
Pupil:	*6 m/s*
Teacher:	*So what is the initial velocity of the train in our problem situation?*
Pupil:	*6 m/s*
Teacher:	*What is the final velocity of the train in the problem?*
Pupil:	*9 m/s*
Teacher:	*Why is it 9 m/s?*
Pupil:	*The train goes past the car with 9 m/s*
Teacher:	*What time does it take the train to go past the car?*
Pupil:	*10 seconds*
Teacher:	*What will be the distance covered by the train?*
Pupil:	*Length of the train*
Teacher:	*Is the length of the train mentioned?*
Pupil:	*No*

Step 3: Planning the solution

Teacher:	*Let us now plan which equation can we use and how can we solve the problem.*
Pupil:	*Yes*
Teacher:	*Which physical quantities are known?*
Pupil:	*We know, initial velocity, u* *final velocity, v* *and time, t*
Teacher:	*What is to be determined?*
Pupil:	*Acceleration, a.*
Teacher:	*So which equation can we use to solve this problem?*
Pupil:	$v = u + at$
Teacher:	*Are all the units in SI system?*
Pupil:	*Yes*
Teacher:	*So, do we have to make unit conversions?*
Pupil:	*No*

Step 4: Implementing the plan

Teacher:	*Now we can proceed according to our plan.* (Teacher work out on the black board) *Substituting the values in equation,* $v = u + at,$ $9 = 6 + a\times10$ Rearranging $a = 3/10$ $=0.3\ m/s^2$

Phase 4: Metacognitive Analysis

Step 1: Error Analysis

Teacher:	*The equation we used is, v= u+ at* *Write the units used for each of the quantities and see whether they are the same for each term on either side of the equation.*
Pupil:	(work out in their books) $v = u + at$ $m/s = m/s + m/s^2 \times s$ $m/s = m/s + m/s$ *The units for all the terms are the same.*
Teacher:	*Therefore the equation is consistent unit wise.*

Step 2: Monitoring the Procedure

Teacher:	*What was your first step while solving the problem?*
Pupil:	*We drew the train and car before and after 10 seconds and showed their velocities*
Teacher:	*Which physical quantities were given directly?*
Pupil:	*Initial velocity, final velocity and time*
Teacher:	*Which physical quantities were to be determined?*
Pupil:	*Acceleration*
Teacher:	*How did you obtain the required relations?*
Pupil:	*We analyzed the equations of motion and decided to use* $v = u + at$
Teacher:	*What assumptions did we make?*
Pupil:	*We have no idea*

Teacher:	*We assumed that the acceleration of the train remains a constant. This is because we can use equations of motion only if the acceleration remains a constant.* *How did you solve the problem?*
Pupil:	*We substituted the given values, rearranged the equations and found acceleration*
Teacher:	*Did you face any difficulty in any stage?*
Pupil:	*No*

Step 3. Analogical Problem Solving

Teacher:	*Now you have to solve the following problem going through all the steps we practiced today.* (Teacher writes the analogical question on the black board) *A car enters a tunnel with a speed of 4 m/s. It takes 55 seconds for the car to come out of the tunnel by which time its velocity is 6 m/s. Calculate the acceleration of the car.*

(Students workout the problem individually or in small groups and report to the teacher)

Lesson 4: Solving Problems Using Equations of Motion II

Name of teacher: Shareeja Ali M C
Class : 11
Unit : Motion in a Straight Line
Time : 1 hour

Objectives: To enable students to

- Draw a schematic diagram representing a given problem situation
- Identify different physical quantities given in a story problem
- Select appropriate equations to solve a problem
- Apply equations of motion to compute an unknown physical quantity

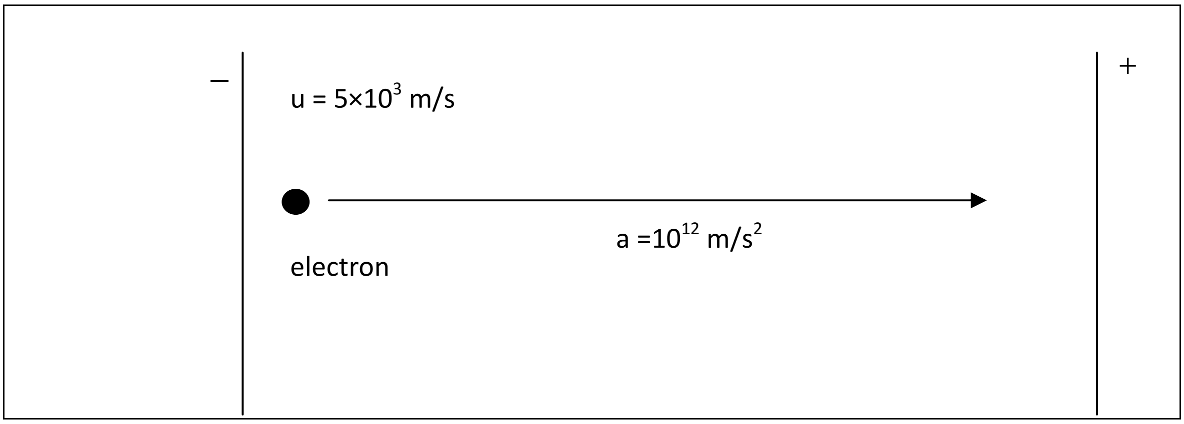
Resources: Concept map, diagrams

Phase 2: Presentation of the Problem

Teacher:	*An electron travelling with a speed of 5×10^3 m/s passes through an electric field with an acceleration of 10^{12} m/s^2. How long will it take the electron to double its speed?*

Phase 3: Problem solving procedure.

Step 1: Surface representation



Step 2: Structure Representation

Teacher:	*Let us discuss the motion of the electron through an electric field. What is the initial velocity of the electron?*
Pupil:	5×10^3 *m/s*
Teacher:	*What is its final velocity?*
Pupil:	10×10^3 *m/s*
Teacher:	*Correct. How did you get final velocity as* 10×10^3 *m/s?*
Pupil:	*It is said in the problem, that the electron attain double its speed.*
Teacher:	*Is the electron accelerating?*
Pupil:	*Yes*
Teacher:	*Why is the electron accelerating?*
Pupil:	*The electron is passing through an electric field.*
Teacher:	*How much is its acceleration?*
Pupil:	10^{12} *m/s*
Teacher:	*How did you label negative and positive plates in the diagram?*
Pupil:	*Electron is negatively charged. So it moves towards the positive plate.*
Teacher:	*What is to be determined?*
Pupil:	*Time*

Step 3: Planning the solution

Teacher:	*Let us now plan which equation can we use and how can we solve the problem.*
Pupil:	*Yes*
Teacher:	*Which physical quantities are known?*
Pupil:	*We know, initial velocity, u* *final velocity, v* *and acceleration, a*
Teacher:	*What is to be determined?*
Pupil:	*Time, t*
Teacher:	*So which equation can we use to solve this problem?*
Pupil:	$v = u + at$
Teacher:	*Are all the units in SI system?*
Pupil:	*Yes*
Teacher:	*So, do we have to make unit conversions?*
Pupil:	*No*

Step 4: Implementing the plan

Teacher:	*Now we can proceed according to our plan.* (Teacher work out on the black board) *Substituting the values in equation,* $v = u + at,$ $10\times10^3 = 5\times10^3 + 10^{12}\times t$ Rearranging $t = (5\times10^3)/10^{12}$ $= 5\times10^{-9}$ *seconds*

Phase 4: Metacognitive Analysis

Step 1: Error Analysis

Teacher:	*The equation we used is, v= u+ at* *Write the units used for each of the quantities and see whether they are the same for each term on either side of the equation.*
Pupil:	(work out in their books) $v = u + at$ $m/s = m/s + m/s^2 \times s$ $m/s = m/s + m/s$ *The units for all the terms are the same.*
Teacher:	*Therefore the equation is consistent unit wise.*

Step 2: Monitoring the Procedure

Teacher:	*What was your first step while solving the problem?*
Pupil:	*We drew the path of an electron trough an electric field and showed its initial and final velocities and acceleration.*
Teacher:	*Which physical quantities were given directly?*
Pupil:	*Initial velocity, final velocity and acceleration*
Teacher:	*Which physical quantities were to be determined?*
Pupil:	*Time*
Teacher:	*How did you obtain the required relations?*
Pupil:	*We analyzed the equations of motion and decided to use* $v = u + at$
Teacher:	*What assumptions did we make?*

Pupil:	*We assumed that the electron moves towards the positive plate in a straight line.*
Teacher:	*How did you solve the problem?*
Pupil:	*We substituted the given values, rearranged the equations and found time*
Teacher:	*Did you face any difficulty in any stage?*
Pupil:	*No*

Step 3. Analogical Problem Solving

Teacher:	*Now you have to solve the following problem going through all the steps we practiced today.* (Teacher writes the analogical question on the black board)
	A proton travelling with a speed of 3×10^2 m/s passes through an electric field with an acceleration of 10^6 m/s^2. How long will it take the proton to attain thrice its original speed?

(Students workout the problem individually or in small groups and report to the teacher)

Lesson 5: Solving Problems Using Equations of Motion III

Name of teacher: Shareeja Ali M C
Class : 11
Topic : Motion in a Straight Line
Time : 1 hour

Objectives: To enable students to

- Draw a schematic diagram representing a given problem situation
- Identify different physical quantities given in a story problem
- Select appropriate equations to solve a problem
- Apply equations of motion to compute an unknown physical quantity

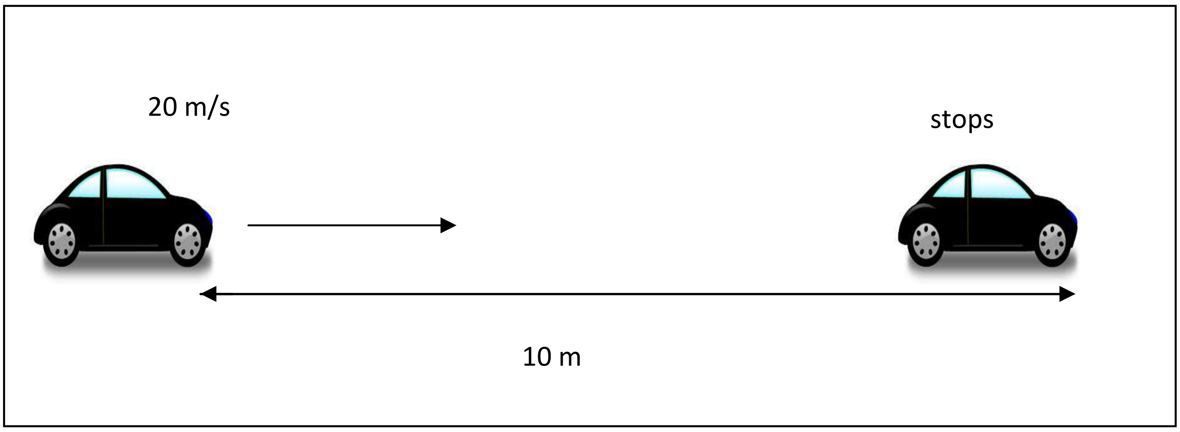
Resources: Concept map, diagrams

Phase 2: Presentation of the Problem

Teacher:	*A motor car moving with a uniform velocity of 20m/s comes to stop on the application of breaks, after travelling a distance of 10m. What is its acceleration?*

Phase 3: Problem solving procedure.

Step 1: Surface representation



Step 2: Structure Representation

Teacher:	*Let us discuss the motion of the car. What is the initial velocity of the car?*
Pupil:	*20 m/s*
Teacher:	*What is its final velocity?*
Pupil:	*Zero*
Teacher:	*Correct. How did you get final velocity as zero?*
Pupil:	*It is said in the problem, that the car comes to stop.*
Teacher:	*What is the distance travelled by the car?*
Pupil:	*10 meters*
Teacher:	*What is to be determined?*
Pupil:	*Acceleration*
Teacher:	*What will be the acceleration? It will be positive or negative?*
Pupil:	*Negative*
Teacher:	*Why do you say it will be negative?*
Pupil:	*When we apply breaks, the velocity of the car decreases. So the acceleration will be negative.*
Teacher:	*What do you call negative acceleration?*
Pupil:	*Deceleration*
Teacher:	*So we can say that the car decelerates*

Step 3: Planning the solution

Teacher:	*Let us now plan which equation can we use and how can we solve the problem.*
Pupil:	*Yes*
Teacher:	*Which physical quantities are known?*
Pupil:	*We know, initial velocity, u* *final velocity, v* *and distance travelled, S*
Teacher:	*What is to be determined?*
Pupil:	*Acceleration*
Teacher:	*So which equation can we use to solve this problem?*
Pupil:	$v^2 = u^2 + 2aS$
Teacher:	*Are all the units in SI system?*
Pupil:	*Yes*
Teacher:	*So, do we have to make unit conversions?*
Pupil:	*No*

Step 4: Implementing the plan

Teacher:	*Now we can proceed according to our plan.*
	(Teacher work out on the black board)
	Substituting the values in equation,
	$v^2 = u^2 + 2aS,$
	$0 = (20)^2 + 2\times a\times 10$
	Rearranging
	$a = -400/20$
	$= -20\ m/s^2$

Phase 4: Metacognitive Analysis

Step 1: Error Analysis

Teacher:	*The equation we used is,* $v^2 = u^2 + 2aS$
	Write the units used for each of the quantities and see whether they are the same for each term on either side of the equation.
Pupil:	(work out in their books)
	$v^2 = u^2 + 2aS$
	$(m/s)^2 = (m/s)^2 + m/s^2 \times m$
	$m^2/s^2 = m^2/s^2 + m^2/s^2$
	The units for all the terms are the same.
Teacher:	*Therefore the equation is consistent unit wise.*

Step 2: Monitoring the Procedure

Teacher:	*What was your first step while solving the problem?*
Pupil:	*We drew the path of the car and showed its initial velocity and distance travelled.*
Teacher:	*Which physical quantities were given directly?*
Pupil:	*Initial velocity and distance travelled*
Teacher:	*Which physical quantities were to be determined?*
Pupil:	*Acceleration*
Teacher:	*How did you obtain the required relations?*
Pupil:	*We analyzed the equations of motion and decided to use*
	$v^2 = u^2 + 2aS$
Teacher:	*What assumptions did we make?*
Pupil:	*We assumed that the final velocity is zero. This is because; the car comes to a stop on the application of breaks.*
Teacher:	*How did you solve the problem?*
Pupil:	*We substituted the given values, rearranged the equations and found acceleration*
Teacher:	*Did you face any difficulty in any stage?*
Pupil:	*No*

Step 3. Analogical Problem Solving

Teacher:	*Now you have to solve the following problem going through all the steps we practiced today.* (Teacher writes the analogical question on the black board)

A train reaches the station with a velocity of 60 m/s. It travels 20m before coming to a halt. What is its acceleration?

(Students workout the problem individually or in small groups and report to the teacher)

Lesson 6: Unit Conversions While Solving Problems

Name of teacher	:	Shareeja Ali M C
Class	:	11
Topic	:	Motion in a Straight Line
Time	:	1 hour

Objectives: To enable students to

- Draw a schematic diagram representing a given problem situation
- Identify different physical quantities given in a story problem
- Convert physical quantities in different units to SI units
- Select appropriate equations to solve a problem
- Compute time taken when distance and speed is given

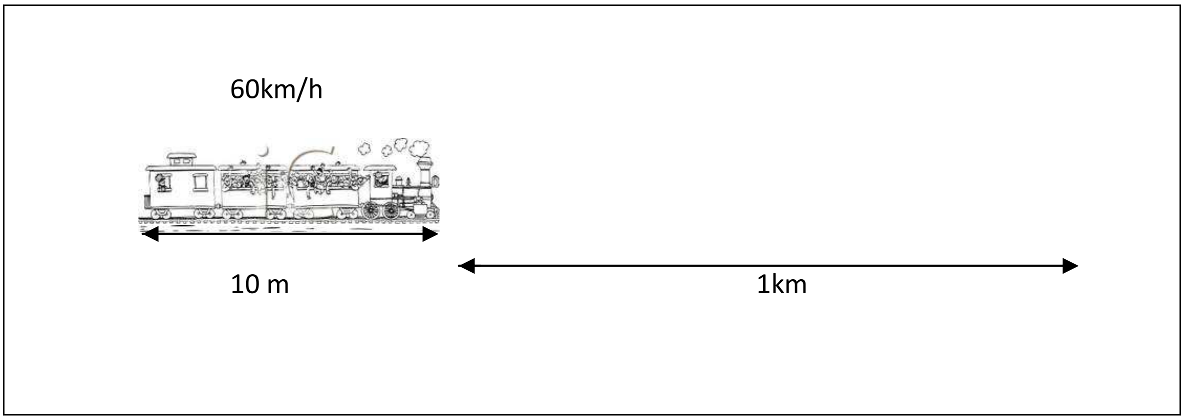
Resources: Concept map, diagrams

Phase 2: Presentation of the Problem

Teacher:	*A train 100 meter long is moving with a speed of 60 km/h. In what time shall it cross a bridge 1 km long?*

Phase 3: Problem solving procedure.

Step 1: Surface representation



Step 2: Structure Representation

Teacher:	*Let us discuss the motion of the train on the bridge. What can be taken as the distance covered?*
Pupil:	*The length of the bridge*
Teacher:	*Is the length of the train negligibly small?*
Pupil:	*No*
Teacher:	*So, we have to take into account the length of the train also. What is the length of the train?*
Pupil:	*100m*
Teacher:	*What is the length of the bridge?*
Pupil:	*1 km*
Teacher:	*Are the length of the train and that of the bridge in the same units?*
Pupil:	*No*
Teacher:	*Then can we add the lengths?*
Pupil:	*No*
Teacher:	*Which one should we convert?*
Pupil:	*Length of the bridge. It is not in SI unit.*
Teacher:	*How can we convert km to meter?*
Pupil:	*1km = 1000m*
Teacher:	*Good. Then convert and find the total distance travelled by the train.*
Pupil:	(Workout in their note books) *Distance = 100m +1km* *= 100m + 1000m* *= 1100m*
Teacher:	*What is the speed of the train?*
Pupil:	*60 km/h*
Teacher:	*Is km/h a SI unit?*
Pupil:	*No*
Teacher:	*How can we convert it?*
Pupil:	(Workout in their note books. Teacher provides guidance to some students) *60 km/h = 60×1000m/60×60 s* *= 16.67 m/s*
Teacher:	*What is to be determined?*
Pupil:	*Time*

<u>Step 3: Planning the solution</u>

Teacher:	*Let us now plan which equation can we use and how can we solve the problem.*
Pupil:	*Yes*
Teacher:	*Which physical quantities are known?*
Pupil:	*We know distance travelled by the train and its speed.*
Teacher:	*What is to be determined?*
Pupil:	*Time, t*
Teacher:	*So which equation can we use to solve this problem?*
Pupil:	*Speed = distance travelled/time*
Teacher:	*Are all the units given in SI system?*
Pupil:	*No*
Teacher:	*Did we convert all the units in to SI?*
Pupil:	*Yes*

<u>Step 4: Implementing the plan</u>

Teacher:	*Now we can proceed according to our plan.* (Teacher work out on the black board) *Substituting the values in equation,* *Speed = distance travelled/time* *16.67 = 1100/time* Rearranging *Time = 1100/16.67* *= 66 seconds*

Phase 4: Metacognitive Analysis

<u>Step 1: Error Analysis</u>

Teacher:	*The equation we used is,* *Speed = distance travelled / time* *Write the units used for each of the quantities and see whether they are the same for each term on either side of the equation.*
Pupil:	(work out in their books) *Speed = distance travelled/time* *m/s = m/s* *The units for all the terms are the same.*
Teacher:	*Therefore the equation is consistent unit wise.*

Step 2: Monitoring the Procedure

Teacher:	*What was your first step while solving the problem?*
Pupil:	*We drew the train and the bridge and showed their lengths and the speed of the train in the diagram*
Teacher:	*Were the physical quantities given directly?*
Pupil:	*Speed was given, but we estimated the distance by adding length of the train and the bridge*
Teacher:	*Which physical quantities were to be determined?*
Pupil:	*Time*
Teacher:	*Which equation did you use?*
Pupil:	*Speed = distance travelled / time*
Teacher:	*were all the equations given in SI?*
Pupil:	*No*
Teacher:	*What unit conversions did you make?*
Pupil:	*We converted km to meter and km/h to m/s*
Teacher:	*How did you solve the problem?*
Pupil:	*We substituted the given values, rearranged the equations and found time*
Teacher:	*Did you face any difficulty in any stage?*
Pupil:	*No*

Step 3. Analogical Problem Solving

Teacher: *Now you have to solve the following problem going through all the steps we practiced today.*

(Teacher writes the analogical question on the black board)

Feroke railway station is 1.5 km long. How long will it take a 150 m long train to pass the station without stopping, if it is travelling with a constant speed of 70 km/h?

(Students workout the problem individually or in small groups and report to the teacher)

<u>Lesson 7: Estimating Average Speed and Average Velocity</u>

Name of teacher	: Shareeja Ali M C
Class	: 11
Topic	: Motion in a Straight Line
Time	: 1 hour

Objectives: To enable students to

- Draw a schematic diagram representing a given problem situation
- Identify different physical quantities given in a story problem
- Select appropriate equations to solve a problem
- Compare and contrast average speed and average velocity
- Compute average speed and average velocity

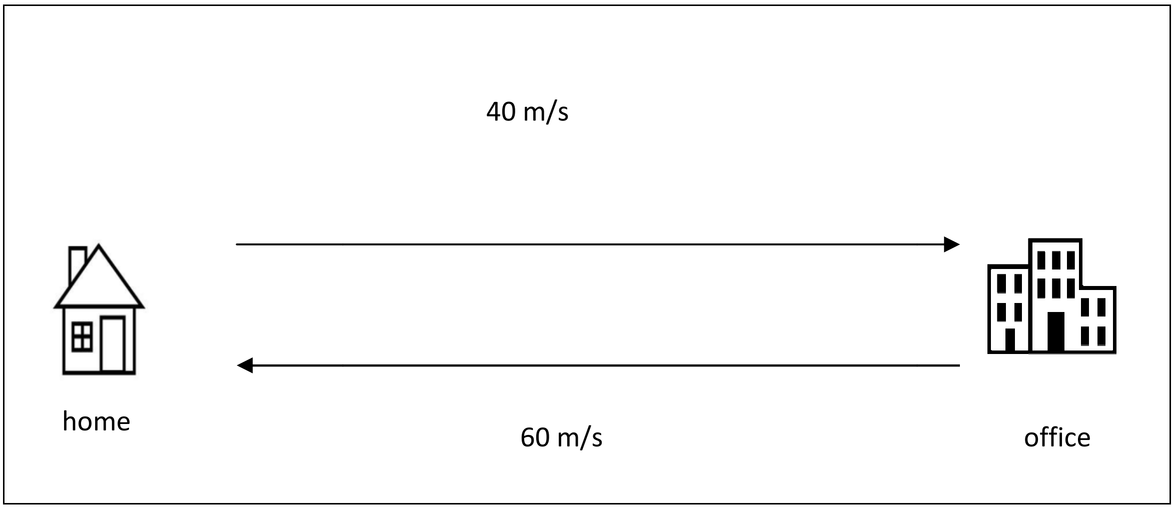
Resources :Concept map, diagrams

Phase 2: Presentation of the Problem

Teacher: *A man travels in his car from home to office at 40 m/s and from office to home at 60 m/s. Calculate average speed and average velocity of that person.*

Phase 3: Problem solving procedure.

<u>Step 1: Surface representation</u>



Step 2: Structure Representation

Teacher:	*Let us discuss the motion of the man to his office and back home. What is his speed when he goes to his office?*
Pupil:	*40 m/s*
Teacher:	*What is his speed when he returns home?*
Pupil:	*60 m/s*
Teacher:	*which physical quantities are to be determined?*
Pupil:	*Average speed and average velocity*
Teacher:	*What is average speed?*
Pupil:	*Path length / time*
Teacher:	*Is the path length and time given?*
Pupil:	*No*
Teacher:	*Then what is given?*
Pupil:	*Two speeds are given*
Teacher:	*True. What is average velocity?*
Pupil:	*Displacement / time*
Teacher:	*What will be the displacement when the person reach back home?*
Pupil:	*Zero*

Step 3: Planning the solution

Teacher:	*Let us now plan how we can solve the problem.*
Pupil:	*Yes*
Teacher:	*Which physical quantities are known?*
Pupil:	*Two speeds*
Teacher:	*Which physical quantities are to be determined?*
Pupil:	*Average speed and average velocity*
Teacher:	*How can we determine average speed from two given speeds?*
Pupil:	*Average speed = (speed 1+speed 2)/2*
Teacher:	*How can we determine average velocity?*
Pupil:	*Average velocity = Displacement/ time*
Teacher:	*Are all the units in SI system?*
Pupil:	*Yes*
Teacher:	*So, do we have to make unit conversions?*
Pupil:	*No*

Step 4: Implementing the plan

Teacher:	*Now we can proceed according to our plan.* (Teacher work out on the black board) *Substituting the values in equation,* *Average speed = (speed 1 + speed 2)/2* *= (40 + 60)/2* *= 100/2* *=50 m/s* *Average velocity = displacement/time* *= 0 m/s*

Phase 4: Metacognitive Analysis

Step 1: Error Analysis

Teacher:	*The equation we used were* *Average speed = (speed 1 + speed 2)/2* *Average velocity = displacement/time* *Write the units used for each of the quantities and see whether they are the same for each term on either side of the equation.*
Pupil:	(work out in their books) *Average speed = (speed 1 + speed 2)/2* *m/s = m/s + m/s* *The units for all the terms are the same.* *Average velocity = displacement/time* *m/s = m/s* *The units for all the terms are the same.*
Teacher:	*Therefore the equation is consistent unit wise.*

Step 2: Monitoring the Procedure

Teacher:	*What was your first step while solving the problem?*
Pupil:	*We drew home and office and showed speed of the man while going to the office and while returning home.*
Teacher:	*Which physical quantities were given directly?*
Pupil:	*Two speeds were given*
Teacher:	*Which physical quantities were to be determined?*
Pupil:	*Average speed and average velocity*

Teacher:	*Which equations were used?*
Pupil:	*The equation we used were* *Average speed = (speed 1 + speed 2)/2* *Average velocity = displacement/time*
Teacher:	*What assumptions did we make?*
Pupil:	*We assumed that the motion was uniform while going to the office and on return*
Teacher:	*Did you face any difficulty in any stage?*
Pupil:	*No*

Step 3. Analogical Problem Solving

Teacher:	*Now you have to solve the following problem going through all the steps we practiced today.* (Teacher writes the analogical question on the black board) *A person drives to the fish market at a speed of 50 km/h and returns home at a speed of 70 km/h. What is the average speed and average velocity of the person?*

(Students workout the problem individually or in small groups and report to the teacher)

Lesson 8: Problems on Relative Velocity I

Name of teacher: Shareeja Ali M C
Class : 11
Unit : Motion in a Straight Line
Time : 1 hour

Objectives: To enable students to

- Draw a schematic diagram representing a given problem situation
- Identify different physical quantities given in a story problem
- Select appropriate equations to solve a problem
- Use the concept of relative velocity to compute unknown time

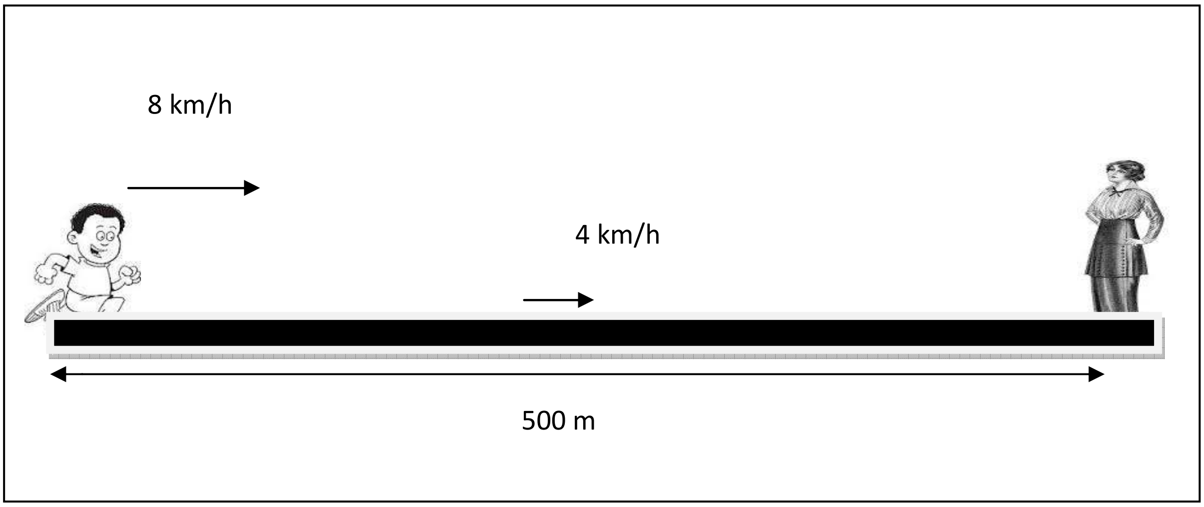
Resources: Concept map, diagrams

Phase 2: Presentation of the Problem

Teacher: *On a horizontally moving belt, a child runs with a speed of 8 km/h towards his mother on the ground 500m away. The belt is moving towards the mother with a speed of 4km/h. In what time will the child reach his mother?*

Phase 3: Problem solving procedure.

Step 1: Surface representation



Step 2: Structure Representation

Teacher:	*Let us discuss the motion of the boy on the moving belt. What is the velocity of the belt?*
Pupil:	*4km/h*
Teacher:	*What is the running speed of the boy?*
Pupil:	*8 km/h*
Teacher:	*What is the distance to be covered by the boy?*
Pupil:	*500m*
Teacher:	*What is to be determined?*
Pupil:	*Time*

Step 3: Planning the solution

Teacher:	*Let us now plan which equation can we use and how can we solve the problem.*
Pupil:	*Yes*
Teacher:	*Which physical quantities are known?*
Pupil:	*We know, the speed of the boy, velocity of the belt, and distance to be covered by the boy.*
Teacher:	*What is to be determined?*
Pupil:	*Time*
Teacher:	*How can we find the velocity with which the boy approaches his mother?*
Pupil:	*Add the speed of the boy and the belt.*
Teacher:	*Why should we add the velocities?*
Pupil:	*Both boy and the belt are moving in the same direction. Boy is on the belt.*
Teacher:	*Correct. Now add and find the velocity of the boy approaching his mother.*
Pupil:	*8 + 4 = 12 km/h*
Teacher:	*Are all the units in SI system?*
Pupil:	*No*
Teacher:	*Which physical quantity is not in SI unit?*
Pupil:	*Velocity. It is in km/h*
Teacher:	*How can we convert km/h in to m/s?*
Pupil:	*1km/h = 1000/60×60 m/s*
Teacher:	*Correct. Now convert 12km/h in to m/s*

Pupil:	(Work out in their books) *12km/h = 12×1000/ 60×60* *= 3.33 m/s*
Teacher:	*Now we know velocity and distance in SI units. Which equation can we use to find time?*
Pupil:	*velocity = distance/ time*

<u>Step 4: Implementing the plan</u>

Teacher:	*Now we can proceed according to our plan.* *(Teacher work out on the black board)* *Substituting the values in equation,* *Velocity= distance/ time* *3.33 = 500/ time* Rearranging *Time= 500/3.33* *=150 seconds*

Phase 4: Metacognitive Analysis

<u>Step 1: Error Analysis</u>

Teacher:	*The equation we used is, velocity = distance/ time* *Write the units used for each of the quantities and see whether they are the same for each term on either side of the equation.*
Pupil:	(work out in their books) *Velocity = distance/ time* *m/s = m/s* *The units for all the terms are the same.*
Teacher:	*Therefore the equation is consistent unit wise.*

<u>Step 2: Monitoring the Procedure</u>

Teacher:	*What was your first step while solving the problem?*
Pupil:	*We drew a diagram showing the boy running on a moving belt towards his mother.*
Teacher:	*Which physical quantities were given directly?*
Pupil:	*Velocity of the belt and the boy, and distance between the boy and his mother.*
Teacher:	*Which physical quantities were to be determined?*
Pupil:	*Time*

Teacher:	*How did you obtain the relative velocity of the boy with respect to his mother?*
Pupil:	*We added the velocity of the belt and the boy.*
Teacher:	*How did you calculate time?*
Pupil:	*We used the equation, velocity = distance/ time*
Teacher:	*Where all the quantities in SI unit?*
Pupil:	*No*
Teacher:	*which physical quantity was not in SI?*
Pupil:	*Velocity*
Teacher:	*What unit conversions did you make?*
Pupil:	*km/ h to m/s*
Teacher:	*How did you convert km/h to m/s?*
Pupil:	*1km/h = 1000/60×60 m/s*
Teacher:	*How did you solve the problem?*
Pupil:	*We substituted the given values, rearranged the equations and found time*
Teacher:	*Did you face any difficulty in any stage?*
Pupil:	*No*

<u>Step 3. Analogical Problem Solving</u>

Teacher: *Now you have to solve the following problem going through all the steps we practiced today.*

(Teacher writes the analogical question on the black board)

A train moves towards a tree, 3km away with a speed of 100km/h. A monkey runs on the train in the same direction with a speed of 10km/h. In what time will the monkey reach the train?

(Students workout the problem individually or in small groups and report to the teacher)

Lesson 9: Problems on Relative Velocity II

Name of teacher	: Shareeja Ali M C
Class	: 11
Topic	: Motion in a Straight Line
Time	: 1 hour

Objectives: To enable students to

- Draw a schematic diagram representing a given problem situation
- Identify different physical quantities given in a story problem
- Select appropriate equations to solve a problem
- Compute relative velocity of bodies moving in opposite directions

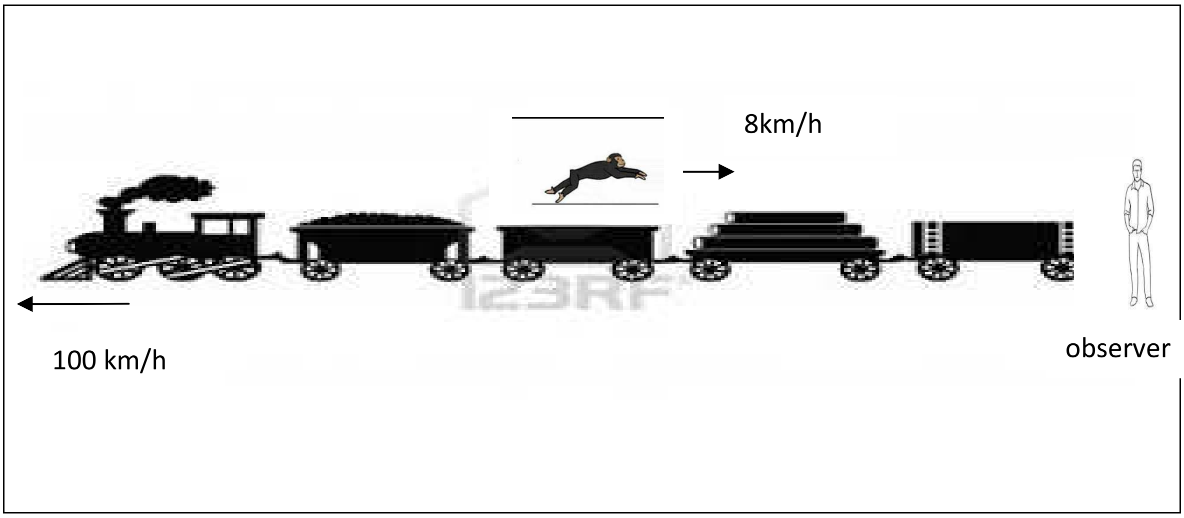
Resources : Concept map, diagrams

Phase 2: Presentation of the Problem

Teacher: *A train moves towards south with a speed of 100km/h. A monkey runs on the train towards north with a speed of 8km/h. What is the relative velocity of the monkey with respect to an observer on the platform?*

Phase 3: Problem solving procedure.

Step 1: Surface representation



Step 2: Structure Representation

Teacher:	*Let us discuss the motion of the monkey on the train. What is the speed of the monkey?*
Pupil:	*8km/h*
Teacher:	*What is the speed of the train?*
Pupil:	*100 km/h*
Teacher:	*Are they moving in the same direction?*
Pupil:	*No*
Teacher:	*Suppose you are standing on the platform. Will you see the monkey moving towards you?*
Pupil:	*No. It will be moving away.*
Teacher:	*Why the monkey will move away even if it is moving towards you?*
Pupil:	*Because the train is moving much faster than the monkey.*
Teacher:	*In which direction is the train moving?*
Pupil:	*Southwards*
Teacher:	*In which direction is the monkey moving?*
Pupil:	*Northwards*
Teacher:	*When you observe the running monkey from the platform, in which direction will it move?*
Pupil:	*Southwards in the direction of the train.*
Teacher:	*Now we have to compute the speed of the monkey relative to the stationary observer on a platform.*

Step 3: Planning the solution

Teacher:	*Let us now plan how we can solve the problem.*
Pupil:	*Yes*
Teacher:	*Which physical quantities are known?*
Pupil:	*Velocity of the train and the monkey.*
Teacher:	*What is to be determined?*
Pupil:	*Velocity of the monkey with respect to the stationary observer.*
Teacher:	*Which equation can we use?*
Pupil:	*Relative velocity = Velocity of the train- Velocity of the monkey.*
Teacher:	*Why do we have to subtract?*
Pupil:	*Because they are moving in opposite directions.*
Teacher:	*Are all the units in SI system?*
Pupil:	*No*
Teacher:	*Do we have to make unit conversions?*
Pupil:	*No*
Teacher:	*Why we don’t have to convert?*
Pupil:	*All units are in km/h. we can compute the answer also in km/h*
Teacher:	*Ok.*

Step 4: Implementing the plan

Teacher:	*Now we can proceed according to our plan.* (Teacher work out on the black board) *Substituting the values in equation,* *Relative velocity = velocity of the train-velocity of monkey* *=100-8* *=92 km/h*
Teacher:	*What is the direction of this velocity?*
Pupil:	*Southwards*

Phase 4: Metacognitive Analysis

Step 1: Error Analysis

Teacher:	*We used the equation* *Relative velocity = velocity of the train- velocity of the monkey* *Write the units used for each of the quantities and see whether they are the same for each term on either side of the equation.*
Pupil:	(work out in their books) *Relative velocity = velocity of the train-velocity of the monkey* *Km/h =km/h – km/h* *The units for all the terms are the same.*
Teacher:	*Therefore the equation is consistent unit wise.*

Step 2: Monitoring the Procedure

Teacher:	*What was your first step while solving the problem?*
Pupil:	*We drew a diagram showing a monkey running on a train towards an observer.*
Teacher:	*Which physical quantities were given directly?*
Pupil:	*velocity of the train and the monkey*
Teacher:	*Which physical quantities were to be determined?*
Pupil:	*Relative velocity of the monkey with respect to the observer.*
Teacher:	*Which equations were used?*
Pupil:	*The equation we used were* *Relative velocity = velocity of the train – velocity of the observer*
Teacher:	*Did you make any unit conversions*
Pupil:	*No*
Teacher:	*How did you find the direction of relative velocity?*

Pupil:	*We assumed it to be in the direction of the train, as it is moving faster.*
Teacher:	*Did you face any difficulty in any stage?*
Pupil:	*No*

Step 3. Analogical Problem Solving

Teacher:	*Now you have to solve the following problem going through all the steps we practiced today.* (Teacher writes the analogical question on the black board) *A train moves towards north with a speed of 80km/h. A kangaroo jumps on the train with a speed of 12km/h towards south. What will be the velocity of the kangaroo with respect to the observer on ground?*

(Students workout the problem individually or in small groups and report to the teacher)

Lesson 10: Problems on Retarded Motion

Name of teacher	:	Shareeja Ali M C
Class	:	11
Topic	:	Motion in a Straight Line
Time	:	1 hour

Objectives: To enable students to

- Draw a schematic diagram representing a given problem situation
- Identify different physical quantities given in a story problem
- Convert physical quantities in different units to SI units
- Select appropriate equations to solve a problem
- Compute time taken for a retarded motion when distance and speed are given

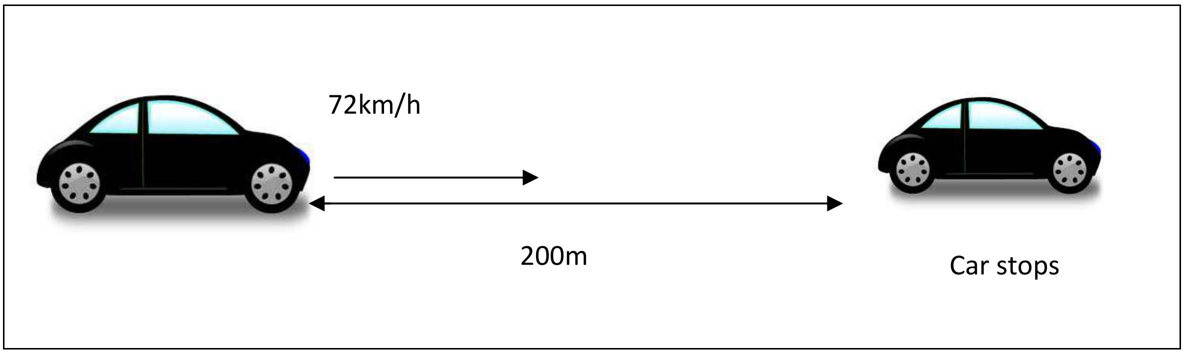
Resources: Concept map, diagrams

Phase 2: Presentation of the Problem

Teacher: *A car moving along a straight road with a speed of 72 km/h stops within a distance of 200m. How long does it take the car to stop?*

Phase 3: Problem solving procedure.

Step 1: Surface representation



Step 2: Structure Representation

Teacher:	*Let us discuss the motion of the car on a straight road. What is the speed of the car?*
Pupil:	*72km/h*
Teacher:	*What happens to the car after sometime?*
Pupil:	*It stops*
Teacher:	*So, what will be its final velocity?*
Pupil:	*Zero*
Teacher:	*Is the car accelerating?*
Pupil:	*No*
Teacher:	*It has negative acceleration. What is negative acceleration called?*
Pupil:	*Deceleration*
Teacher:	*Yes, and the car is said to have retarded motion. What is the distance travelled by the car before stopping?*
Pupil:	*200m*
Teacher:	*Like distance, are all the given units in SI?*
Pupil:	*No*
Teacher:	*Do we have to convert any unit?*
Pupil:	*Yes*
Teacher:	*Which unit do we have to convert?*
Pupil:	*km/h to m/s*
Teacher:	*How can we convert km/h to m/s?*
Pupil:	$1\ km/h = 1000/\ 60\times60\ m/s$
Teacher:	*Good. Now convert 72km/h in to m/s*
Pupil:	(Workout in their note books) $72\ km/h = 72\times1000/\ 60\times60$ $=20\ m/s$
Teacher:	*Correct*

Step 3: Planning the solution

Teacher:	*Let us now plan which equation can we use and how can we solve the problem.*
Pupil:	*Yes*
Teacher:	*Which physical quantities are given?*
Pupil:	*Initial velocity and distance*
Teacher:	*Which physical quantities were assumed?*
Pupil:	*Final velocity*
Teacher:	*What is to be determined?*

Pupil:	*Time*
Teacher:	*We have initial velocity (u), distance (s), and final velocity. Can we find time using any one of the three equations of motion?*
Pupil:	*No*
Teacher:	*What is to be calculated first?*
Pupil:	*Acceleration*
Teacher:	*Or retardation in this case. Which equation can we use?*
Pupil:	$v^2 = u^2 + 2aS$
Teacher:	*Correct. Once we get acceleration, which equation can we use to find time?*
Pupil:	$v = u+at$
Teacher:	*correct*

Step 4: Implementing the plan

Teacher:	*Now we can proceed according to our plan.* (Teacher work out on the black board) *Substituting the values in equation,* $V^2 = u^2 + 2aS$ $0 = (20)^2 + 2\times a\times 200$ $0 = 400+400a$ Rearranging $a= -400/400$ $=-1\ m/s^2$ *Substituting in the second equation* $v= u +at$ $0 = 20+ (-1)\times t$ $0 = 20-t$ Rearranging, *Time = 20 seconds*

Phase 4: Metacognitive Analysis

Step 1: Error Analysis

Teacher:	*The equation we used was,*
	$$v^2 = u^2 + 2aS$$
	Write the units used for each of the quantities and see whether they are the same for each term on either side of the equation.
Pupil:	(work out in their books)
	$$v^2 = u^2 + 2aS$$
	$$(m/s)^2 = (m/s)^2 + m/s^2 \times m$$
	The units for all the terms are the same.
Teacher:	*Therefore the equation is consistent unit wise.*
	We also used the equation,
	$$v = u + at$$
	Write the units used for each of the quantities and see whether they are the same for each term on either side of the equation.
Pupil:	(work out in their books)
	$$v = u + at$$
	$$m/s = m/s + m/s^2 \times s$$
	$$m/s = m/s + m/s$$
	The units for all the terms are the same.
Teacher:	*Therefore the equation is unit wise consistent*

Step 2: Monitoring the Procedure

Teacher:	*What was your first step while solving the problem?*
Pupil:	*We drew a diagram showing the car and labeled its initial velocity and distance travelled.*
Teacher:	*Were the physical quantities given directly?*
Pupil:	*No. We had to assume final velocity as zero, since the car stops.*
Teacher:	*Which physical quantities were to be determined?*
Pupil:	*Time*
Teacher:	*Which equation did you use?*
Pupil:	*We used two equations of motion,*
	$$v^2 = u^2 + 2aS$$
	and
	$$v = u + at$$
Teacher:	*were all the equations given in SI?*
Pupil:	*No*
Teacher:	*What unit conversions did you make?*
Pupil:	*We converted km/h to m/s*
Teacher:	*How did you solve the problem?*

Pupil:	*We substituted the given values, rearranged the equations and found time*
Teacher:	*Did you face any difficulty in any stage?*
Pupil:	*No*

Step 3. Analogical Problem Solving

Teacher:	*Now you have to solve the following problem going through all the steps we practiced today.* (Teacher writes the analogical question on the black board)
	An airplane lands with a horizontal velocity of 144km/h and comes to stop with in a distance 400m on ground. How long does it take the airplane to stop?

(Students workout the problem individually or in small groups and report to the teacher)

Lesson 11: Circular Motion

Name of teacher:		Shareeja Ali M C
Class	:	11
Unit	:	Motion in a Plane
Time	:	1 hour

Objectives: To enable students to

- Cite examples for motion in plane
- Rewrite equations of motion in two dimensions separately
- Describe Circular motion
- Describe uniform circular motion
- Define centripetal acceleration
- Compute centripetal acceleration
- Define angular velocity
- Compute angular velocity

Resources: Concept map, thread, stone, bottle of water

Phase 1: Presentation of Knowledge domain.

(The concept map for the unit, 'Motion in a Plane' developed during the lesson is shown in figure.)

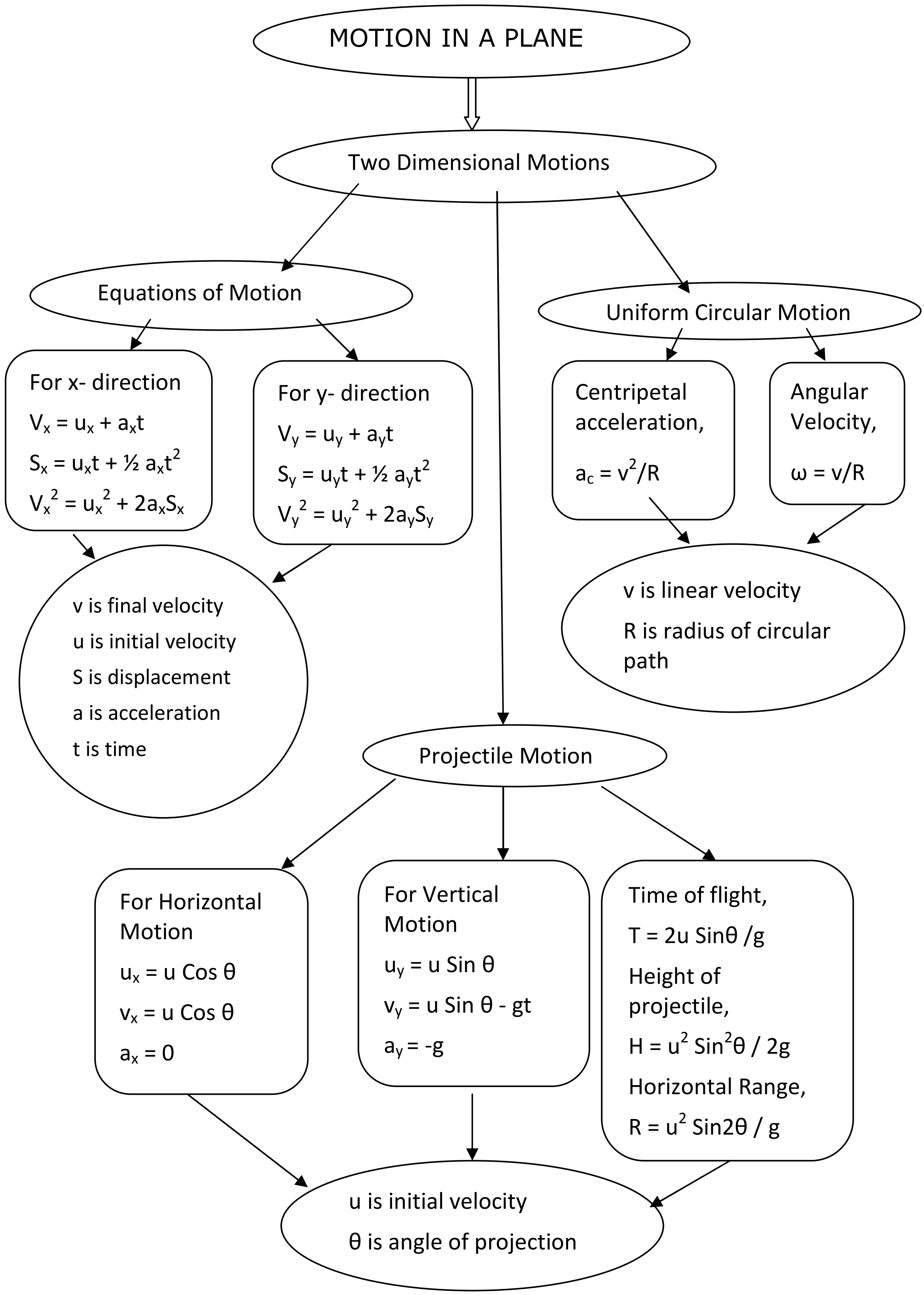


***Figure:** Concept map for the unit 'Motion in a Plane'*

Teacher:	*We have learned about motion and solved some problems to find out velocity, acceleration, time and distance.* *Suppose an ant is moving on a globe, can we use the same equations to find out its distance, speed etc…*
Pupil:	*Not sure*
Teacher:	(Puts a point on the board and asks) *How can we find the position of this point? How many co-ordinates do we need to exactly locate its position?*
Pupil:	*Two. X and Y co-ordinates*
Teacher:	*Correct. Similarly, when an insect moves on this board, we will need its velocity, acceleration, distance etc… in two dimensions. In X and Y, or in horizontal and vertical directions. Such motions are called two dimensional or motion in a plane.*
(Teacher moves a chalk piece on the board. 2meters horizontally (in X direction) and 3 meters vertically (in Y direction))	
	Now, what is the horizontal displacement of the chalk?
Pupil:	*2 meters*
Teacher:	*correct. What is the vertical displacement of the chalk?*
Pupil:	*3 meters*
Teacher:	(Takes the chalk diagonally to the same position in one second) *Now can you guess the horizontal velocity?*
Pupil:	*2m/1s = 2m/s*
Teacher:	*That is correct. Can you guess the vertical velocity?*
Pupil:	*3m/1s = 3m/s*
Teacher:	*Correct.* *Just as you used the equation,* *velocity = distance / time* *in two dimensions separately. You can apply each of the three equations of motions in two dimensions separately.* *What are the three equations of motion?*
Pupil:	$v = u + at$ $S = ut + ½ at^2$ $v^2 = u^2 + 2aS$
Teacher:	(Writes the equations on board and asks) *Can you now write the equations separately for X and Y directions? You just have to put subscripts X and Y for velocities distance and acceleration.* *Will time change in two directions?*
Pupil:	*No*
Teacher:	*So, do you need to put subscripts for time?*
Pupil:	*No*
Teacher:	*Now write equations of motion in X and Y directions separately.*
Pupil:	(Write in their note books. Teacher gives guidance to some children) *For X direction (Horizontal)*

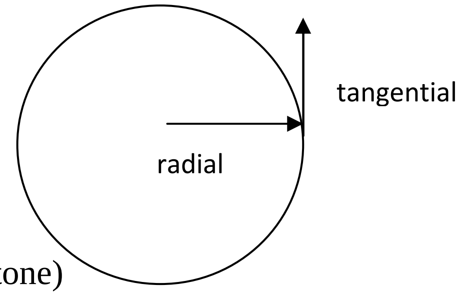
$$v_x = u_x + a_x t$$
$$S_x = u_x\, t + ½\, a_x t^2$$
$$v_x^2 = u_x^2 + 2a_x S_x$$
For Y direction (Vertical)
$$v_y = u_y + a_y t$$
$$S_y = u_y t + ½\, a_y t^2$$
$$v_y^2 = u_y^2 + 2a_y S_y$$

Teacher: (Teacher ties a stone on a rope and rotates it) *Can you guess what type of motion is this? Is this motion in a straight line or in a plane?*

Pupil: *It is not a straight line motion. We are not sure it is motion in a plane.*

Teacher: *This is motion in a plane, or two dimensional motions. The dimensions in this case are radial i.e., along the radius of its path and tangential, i.e., along the tangent of the circle.*

(Teacher draws on the board)



(Teacher again rotates the stone)

Teacher: *I am rotating the stone with constant speed. Is its velocity changing?*

Pupil: *No*

Teacher: *Is the direction of velocity changing?*

Pupil: *Yes*

Teacher: *So its velocity changes. Therefore it has acceleration. This acceleration is called centripetal acceleration. It can be computed using the equation,*

$$a_c = v^2/R,$$

where v is the linear velocity and R is the radius.
In the case of the rotating stone, what will be the radius?

Pupil: *Length of the thread*

Teacher: *Very good. Suppose this thread is 2m long and the stone is rotating with a linear velocity of 4 m/s. Compute the centripetal acceleration of the stone.*

Pupil: (Work out in their books. Teacher provides help to some children)

$$a_c = v^2/R$$
$$=4^2/2$$
$$=16/2$$
$$=8\ m/s^2$$

Teacher:	*Just like centripetal acceleration, it have angular velocity, which is defined as ,* $\omega = v/R$ *Can you compute the angular velocity of the stone?*
Pupil:	(Work out in their books. Teacher provides help to some children) $\omega = v/R$ $= 4/2$ $=2$
Teacher:	*Correct, but what will be the unit of angular velocity?*
Pupil:	*Not sure*
Teacher:	*When a body moves in a straight line, its distance change with time. So the unit of velocity is that of distance/ time. i.e., m/s. When a stone moves in a circle, its angle changes with time. What is the SI unit of angle?*
Pupil:	*Radians*
Teacher:	*Therefore the unit of angular velocity is radians/second.*
(Teacher summarizes the topics covered, completes the concept map and asks some assessment questions)	
Teacher:	*Give few examples for motion in a plane.* *What is the equation to compute centripetal acceleration?* *What is the equation to compute angular velocity?* *What is the unit of angular velocity?*

Lesson 12: Projectile Motion

Name of teacher:		Shareeja Ali M C
Class	:	11
Topic	:	Motion in a Plane
Time	:	1 hour

Objectives: To enable students to

- Identify projectile motion as two dimensional
- Cite examples for projectile motion
- Compute initial and final velocity of a projectile in horizontal direction
- Compute initial and final velocity of a projectile in vertical direction
- Estimate time of flight of a projectile
- Estimate height of a projectile
- Estimate horizontal range of a projectile

Resources: Concept map, diagrams

Phase 1: Presentation of the knowledge domain

(Teacher refreshes the topics covered in the previous lesson while retracing the concept map already drawn)

Teacher: *Do you like cricket?*

Pupil: Yes

Teacher: *Can you draw the path of the ball when a (1) bowler throws it?*

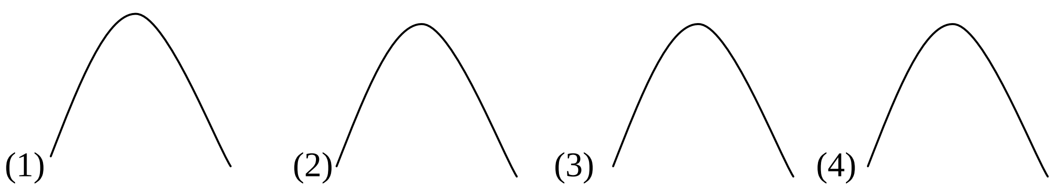
Pupil: (Draws the path of the ball in their note book)

Teacher: *Correct. Can you draw the path of the ball when a (2) batsman strikes it?*

Pupil: (Draws the path of the ball in their note book)

Teacher: *Excellent.*
Now try to draw the path of the
(3) ball, when a football is kicked.
(4) a javelin is thrown.

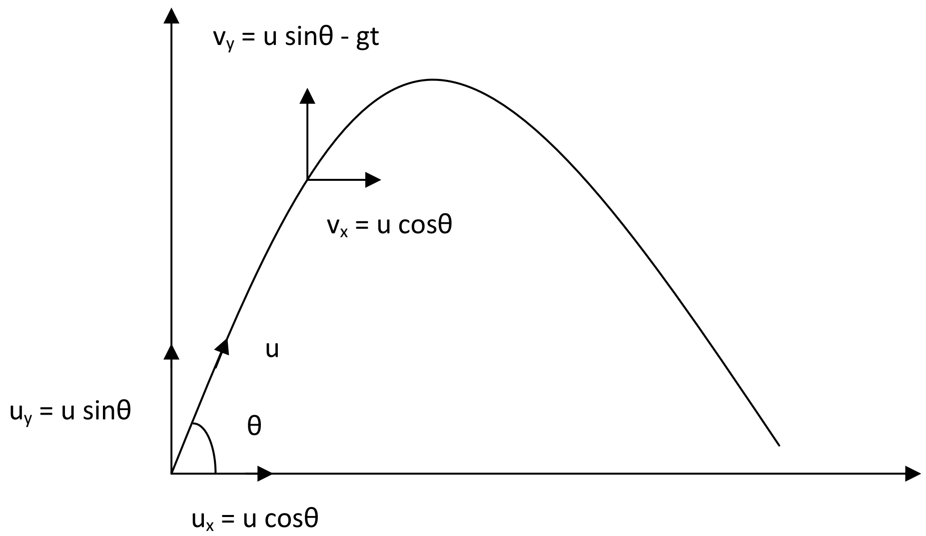
Pupil: (Draws the path of the ball in each case in their note book)



Teacher: *Good*

In each of these cases the ball's trajectory is a parabola. This type of motion is called projectile motion. It is a two dimensional motion or motion in a plane. The projectile motion is characterized by an initial velocity (u) and angle of projection (θ). We can determine the velocity (v) at any time (t) in both horizontal and vertical dimensions using the following equations.

(Teacher draws on the board)



Teacher: *When the body is in air, what is the acceleration on the body?*

Pupil: *Gravity*

Teacher: *Yes, it is acceleration due to gravity (g). In which direction is it acting?*

Pupil: *Downwards*

Teacher: *It is acting downwards or in the vertical direction. Therefore we can write*

$$a_y = -g$$

Is there any acceleration in the horizontal direction?

Pupil: *No*

Teacher: *Therefore we can write*

$$a_x = 0$$

Suppose a ball is thrown with an initial velocity of 4m/s, making an angle of 30^0 with the horizontal. Can you estimate the initial velocity in X and Y directions?

Pupil: (Workout in their note book. Teacher offers guidance to some students)

$$u_x = u\ Cos\theta$$
$$= 4\times\ Cos30$$
$$= 4\times 0.866$$
$$=3.464\ m/s$$
$$u_y = u\ Sin\theta$$
$$= 4\times Sin30$$
$$=4\times 0.5$$
$$=2m/s$$

Teacher: *Correct. Now can you estimate velocity of the ball in x and y directions after 0.2 seconds?*

Pupil: (Workout in their note book. Teacher offers guidance to some students)

$$v_x = u\ Cos\theta$$
$$= 4\times Cos30$$
$$=4\times 0.866$$
$$=3.464\ m/s$$
$$v_y = u\ Sin\theta - gt$$
$$=4\times Sin30 - 9.8\times 0.2$$
$$=2-1.96$$
$$=0.04m/s$$

Teacher: *Correct. You can see that the horizontal velocity or velocity in the x-direction does not change. Why is it not changing?*

Pupil: *Because there is no acceleration*

Teacher: *Good. You can see that the vertical velocity or velocity in y-direction decreases. Why is it decreasing?*

Pupil: *The ball accelerates due to gravity downwards.*

Teacher: *Excellent.*

Once thrown, the time for which the ball remains in air is called the time of flight. We can estimate it using the equation,

$$T = 2u\ Sin\theta\ /g$$

Can you estimate the time of flight of the ball thrown with initial velocity 40m/s making 30^0 with the x-axis?

Pupil: (Workout in their note book. Teacher offers guidance to some students)

$$T=2u\ Sin\theta\ /g$$
$$= (2\times 40\times Sin30)/9.8$$
$$= 4.08\ seconds$$

Teacher: *Correct.*

	The maximum height reached by the projectile can be estimated using the equation,
	$H = u^2 Sin^2\theta/2g$
	Can you estimate the maximum height of the ball thrown with initial velocity 40m/s making 30^0 with the horizontal?
Pupil:	(Workout in their note book. Teacher offers guidance to some students)
	$H = u^2 Sin^2\theta/2g$
	$= (40)^2 (Sin\ 30)^2/2\times9.8$
	$= (1600\times0.25)/19.6$
	$= 20.4\ m$
Teacher:	*Correct*
	The distance covered by the ball on ground when it falls is called the horizontal range. It can be estimated using the equation,
	$R= u^2 Sin2\theta /g$
	Can you estimate the horizontal range of a ball thrown with an initial velocity of 40m/s making 30^0 with the horizontal?
Pupil:	(Workout in their note book. Teacher offers guidance to some students)
	$R= u^2 Sin2\theta /g$
	$= [(40)^2 Sin\ (2\times30)]/9.8$
	$= (1600\times0.866)/9.8$
	$= 141.39m$
Teacher:	*Correct. Similarly, we can use these equations in different situations.*
	Let us now summarize what we learned today and in the last lesson.
(Teacher summarizes the lesson and asks a few questions for reinforcement)	
	Give some examples for projectile motion.
	What will be the horizontal acceleration of a projectile?
	What will be the vertical acceleration of a projectile?
	What is time of flight of a projectile?
	What is horizontal range of a projectile?

(Teacher completes the concept map and asks students to understand and copy that in their note books)

Lesson 13: Time of Flight of a Projectile

Name of teacher: Shareeja Ali M C
Class : 11
Unit : Motion in a Plane
Time : 1 hour

Objectives: To enable students to

- Draw a schematic diagram representing a given problem situation
- Identify different physical quantities given in a story problem
- Select appropriate equations to solve a problem
- Apply equations of motion to compute time of flight of a projectile

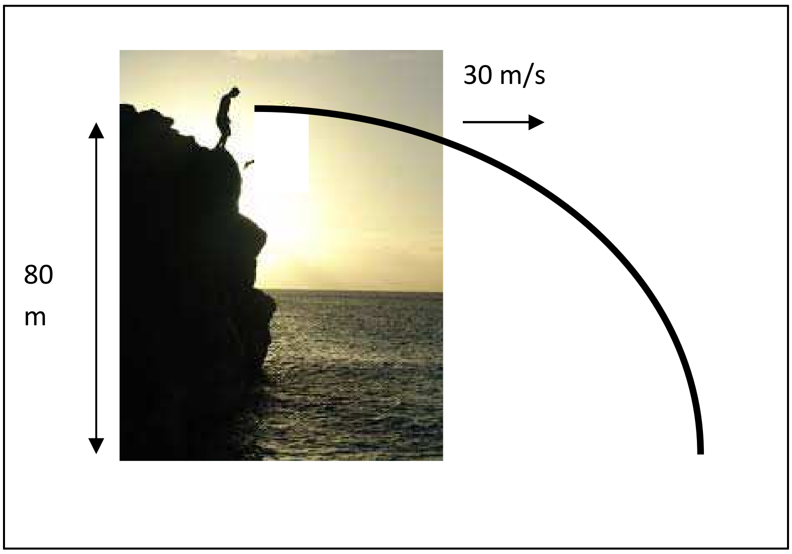
Resources: Concept map, diagrams

Phase 2: Presentation of the Problem

Teacher:	*A projectile is fired with a horizontal velocity of 330m/s from the top of a cliff 80m high. How long will it take the projectile to strike the level ground at the base of the cliff?*

Phase 3: Problem solving procedure.

Step 1: Surface representation



Step 2: Structure Representation

Teacher:	*Let us discuss the motion of the projectile in horizontal and vertical directions. What is the horizontal velocity of the projectile?*
Pupil:	*330 m/s*
Teacher:	*What is the horizontal distance travelled?*
Pupil:	*Unknown*
Teacher:	*What is the initial vertical velocity?*
Pupil:	*Unknown*
Teacher:	*Is said in the problem that the projectile is fired horizontally. So its vertical velocity can be taken as zero. What is the vertical distance covered by the projectile?*
Pupil:	*Height of the cliff, i.e., 80m.*
Teacher:	*What is the vertical acceleration of the projectile?*
Pupil:	$-9.8 m/s^2$
Teacher:	*What is the horizontal acceleration of the projectile?*
Pupil:	*Zero*

Step 3: Planning the solution

Teacher:	*Let us now plan which equation can we use and how can we solve the problem.*
Pupil:	*Yes*
Teacher:	*Which are the known vertical quantities?*
Pupil:	*We know, initial velocity, u* *Acceleration, a* *and distance, S*
Teacher:	*Which are the known horizontal quantities?*
Pupil:	*We know, initial velocity, u* *And, acceleration, a*
Teacher:	*What is to be determined?*
Pupil:	*Time, t*
Teacher:	*So which equation can we use to solve this problem?*
Pupil:	$S = ut + ½ at^2$
Teacher:	*In horizontal or vertical directions?*
Pupil:	*Vertical*
Teacher:	*Why can't we use it in horizontal direction?*
Pupil:	*Because distance covered by the projectile is not known*

Teacher:	*Are all the units in SI system?*
Pupil:	*Yes*
Teacher:	*So, do we have to make unit conversions?*
Pupil:	*No*

Step 4: Implementing the plan

Teacher:	*Now we can proceed according to our plan.* *(Teacher work out on the black board)* *Substituting the values in equation,* $S = ut + ½\ at^2$, $80 = 0 + ½ \times -9.8 \times t^2$ $80 = -4.9t^2$ Rearranging $t^2 = 80/4.9$ $=16.33$ t=4.04 seconds

Phase 4: Metacognitive Analysis

Step 1: Error Analysis

Teacher:	*The equation we used is,* $S=ut + ½\ at^2$ *Write the units used for each of the quantities and see whether they are the same for each term on either side of the equation.*
Pupil:	(work out in their books) $S = ut + ½\ at^2$ $m = m/s \times s + m/s^2 \times s^2$ $m=m + m$ *The units for all the terms are the same.*
Teacher:	*Therefore the equation is consistent unit wise.*

Step 2: Monitoring the Procedure

Teacher:	*What was your first step while solving the problem?*
Pupil:	*We drew a diagram showing a boy on a cliff throwing a projectile.*
Teacher:	*Which physical quantities were given directly?*

Pupil:	*Initial velocity of the projectile in horizontal direction and height of the cliff*
Teacher:	*Which physical quantities were to be determined?*
Pupil:	*Time of flight of the projectile*
Teacher:	*What physical quantities did you assume?*
Pupil:	*Initial velocity in vertical direction, and vertical acceleration*
Teacher:	*How did you obtain the required relations?*
Pupil:	*We analyzed the equations of motion in two dimensions and decided to use* $S = ut + ½ at^2$ *in vertical direction.*
Teacher:	*How did you solve the problem?*
Pupil:	*We substituted the given values, rearranged the equations and found acceleration*
Teacher:	*Did you face any difficulty in any stage?*
Pupil:	*No*

Step 3. Analogical Problem Solving

Teacher:	*Now you have to solve the following problem going through all the steps we practiced today.* (Teacher writes the analogical question on the black board) *An aircraft 500m above ground is flying with a horizontal velocity 15m/s. It drops a bomb. How long will it take the bomb to reach the ground?*

(Students workout the problem individually or in small groups and report to the teacher)

Lesson 14: Horizontal Range and Maximum Height of a Projectile

Name of teacher: Shareeja Ali M C
Class : 11
Unit : Motion in a Plane
Time : 1 hour

Objectives: To enable students to

- Draw a schematic diagram representing a given problem situation
- Identify different physical quantities given in a story problem
- Select appropriate equations to solve a problem
- Describe the angles of projection for maximum height and maximum horizontal range
- Use equations for horizontal range and maximum height of a projectile

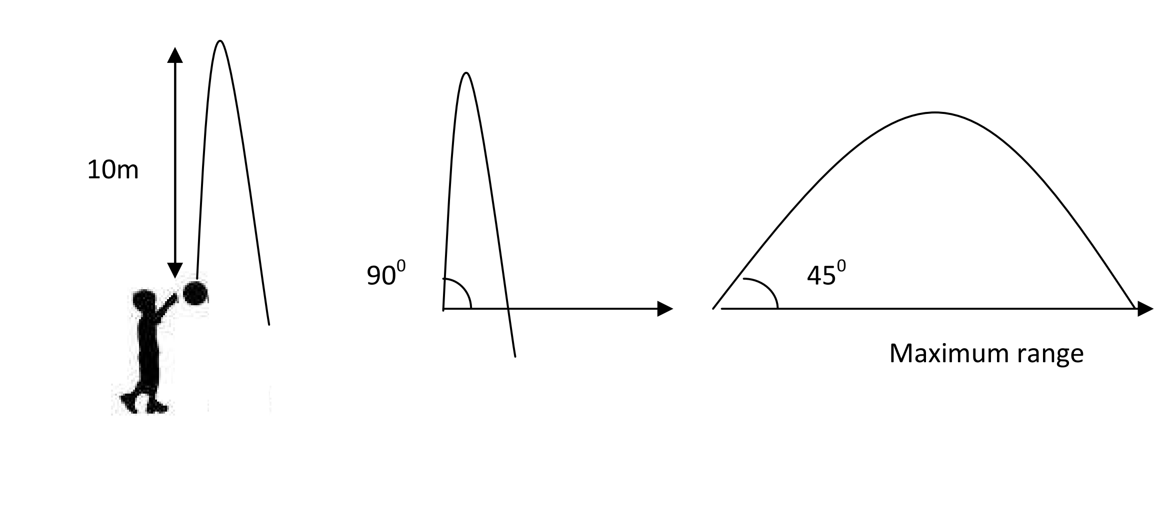
Resources: Concept map, diagrams

Phase 2: Presentation of the Problem

Teacher:	*A boy can throw up a ball to a maximum height of 10m. To what distance can he throw the same ball on the ground?*

Phase 3: Problem solving procedure.

Step 1: Surface representation



Step 2: Structure Representation

Teacher:	*Let us discuss the motion of the ball. What is the maximum height the ball can reach?*
Pupil:	*10m*
Teacher:	*Is any other physical quantity given?*
Pupil:	*No*
Teacher:	*What should be the angle of projection to reach maximum height?*
Pupil:	*It should be thrown upwards.*
Teacher:	*When the ball is thrown vertically upwards, its angle with the horizontal will be* 90^0*. So what is the angle of projection for maximum height?*
Pupil:	90^0
Teacher:	*What is to be determined?*
Pupil:	*Maximum possible horizontal range.*
Teacher:	*what should be the angle of projection for maximum horizontal range?*
Pupil:	45^0

Step 3: Planning the solution

Teacher:	*Let us now plan which equation can we use and how can we solve the problem.*
Pupil:	*Yes*
Teacher:	*Which physical quantity is given?*
Pupil:	*Maximum height*
Teacher:	*What is the angle of projection for maximum height?*
Pupil:	90^0
Teacher:	*what is the equation for height of the projectile?*
Pupil:	$H = u^2 Sin^2\theta/2g$
Teacher:	*We know H, θ and g. what is the unknown quantity in this equation?*
Pupil:	*Initial velocity, u*
Teacher:	*So, we can find u using the equation for height of the projectile. What is asked to find out in the problem?*
Pupil:	*Maximum possible horizontal range*
Teacher:	*What is the equation for horizontal range?*
Pupil:	$R = u^2 Sin2\theta/g$
Teacher:	*Do we know u, θ, and g?*
Pupil:	*Yes*
Teacher:	*are u and g in SI units?*
Pupil:	*Yes*

Step 4: Implementing the plan

Teacher:	*Now we can proceed according to our plan.* (Teacher work out on the black board) *To find initial velocity, substituting the values in equation,* $H = u^2 Sin^2\theta/2g$ $10 = u^2 (\text{Sin } 90)^2/2\times9.8$ $= u^2/19.8$ Rearranging $u^2 = 10\times19.8$ $= 198$ *Therefore,* $u = 14$ *m/s* *To find maximum range, substituting in equation* $R = u^2 Sin2\theta/g$ $= (14)^2 Sin (2\times45)/9.8$ $= 198/9.8$ $=20.2m$

Phase 4: Metacognitive Analysis

Step 1: Error Analysis

Teacher:	*The equation we used is,* $R=u^2 Sin2\theta/g$ *Write the units used for each of the quantities and see whether they are the same for each term on either side of the equation.*
Pupil:	(work out in their books) $m =(m/s)^2 /(m/s^2)$ $m = m$ *The units for all the terms are the same.*
Teacher:	*Therefore the equation is consistent unit wise.*

Step 2: Monitoring the Procedure

Teacher:	*What was your first step while solving the problem?*
Pupil:	*We drew the path of the ball as is goes the highest point and realized that the angle of projection will be* 90^0
Teacher:	*Which physical quantities were given directly?*
Pupil:	*The maximum possible height of the ball*
Teacher:	*Which physical quantities were to be determined?*

Pupil:	*the maximum horizontal range*
Teacher:	*How did you obtain the required relations?*
Pupil:	*We analyzed the equations for height of a projectile and horizontal range of the projectile*
Teacher:	*What assumptions did we make?*
Pupil:	*We assumed that the angle of projection for maximum height is* 90^0 *and that for maximum range is* 45^0
Teacher:	*How did you solve the problem?*
Pupil:	*We substituted the given values, rearranged the equations and found horizontal range*
Teacher:	*Did you face any difficulty in any stage?*
Pupil:	*Only in the begining*

Step 3. Analogical Problem Solving

Teacher:	*Now you have to solve the following problem going through all the steps we practiced today.* (Teacher writes the analogical question on the black board) *A kangaroo can jump to a maximum height of 5m. To what maximum distance can it jump on ground?*

(Students workout the problem individually or in small groups and report to the teacher)

Lesson 15: Uniform Circular Motion

Name of teacher: Shareeja Ali M C
Class : 11
Topic : Motion in a Plane
Time : 1 hour

Objectives: To enable students to

- Draw a schematic diagram representing a given problem situation
- Identify different physical quantities given in a story problem
- Select appropriate equations to solve a problem
- Compute linear velocity and hence angular velocity

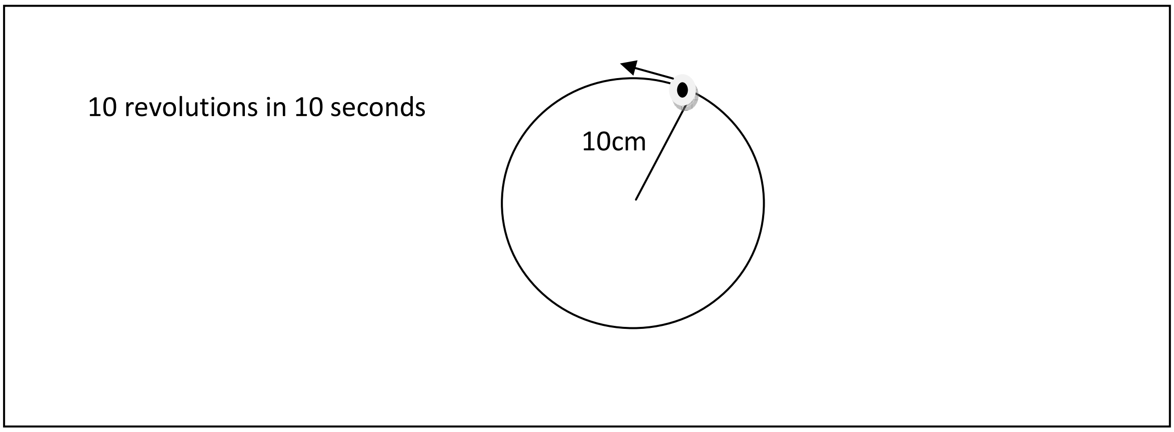
Resources: Concept map, diagrams

Phase 2: Presentation of the Problem

Teacher:	*a boy revolves a stone on a string 10cm long steadily, completing 10 revolutions in 10 seconds. What is the angular speed of the stone?*

Phase 3: Problem solving procedure.

Step 1: Surface representation



Step 2: Structure Representation

Teacher:	*What are the quantities given in the problem?*
Pupil:	*Length of the string, number of revolutions made and time*
Teacher:	*What is to be determined?*
Pupil:	*Angular velocity*
Teacher:	*Are all the quantities in SI unit?*
Pupil:	*No*
Teacher:	*What is not in SI unit?*
Pupil:	*Length of the string. It is in centimeter.*
Teacher:	*How can we convert centimeter to meter?*
Pupil:	*1 cm = 1/100 m*
Teacher:	*Then convert 10 cm to meter*
Pupil:	*(Workout in their books)*
	10 cm = 10/100 m
	=0.1 m

Step 3: Planning the solution

Teacher:	*Let us now plan which equation can we use and how can we solve the problem.*
Pupil:	*Yes*
Teacher:	*What is to be determined?*
Pupil:	*Angular velocity*
Teacher:	*What is the equation to find angular velocity?*
Pupil:	$\omega = v/R$
Teacher:	*Do you know linear velocity, v?*
Pupil:	*No*
Teacher:	*What is the circumference of a circle, or the distance covered by a body when it makes one complete revolution?*
Pupil:	$2\pi R$
Teacher:	*Then what will be the distance covered when the body makes 10 revolutions?*
Pupil:	$2\pi R\times 10$
Teacher:	*What is the time taken for this motion?*
Pupil:	*10 seconds*
Teacher:	*Now you know the distance is* $2\pi R\times 10$ *and time is 10 seconds. So calculate velocity.*
Pupil:	$2\pi R\times 10/10 = 2\pi R$

Step 4: Implementing the plan

Teacher:	*Now we can proceed to calculate angular velocity* (Teacher work out on the black board) *Substituting the values in equation,* $\omega = v/R$ $= 2\pi R/R$ $= 2\pi$ $= 2\times 3.14$ *= 6.28 radians/seconds*

Phase 4: Metacognitive Analysis

Step 1: Error Analysis

Teacher:	*The equation we used is,* $\omega = (2\pi R)/(time\times R)$ *Write the units used for each of the quantities and see whether they are the same for each term on either side of the equation.*
Pupil:	(work out in their books) *Radians/s = (radians×m)/(s×m)* *Radians/s = radians/s* *The units for all the terms are the same.*
Teacher:	*Therefore the equation is consistent unit wise.*

Step 2: Monitoring the Procedure

Teacher:	*What was your first step while solving the problem?*
Pupil:	*We drew the circular path of the stone*
Teacher:	*Which physical quantities were given directly?*
Pupil:	*length of the string, number of revolutions made and time taken*
Teacher:	*Which physical quantities were to be determined?*
Pupil:	*angular velocity*
Teacher:	*How did you obtain the required relations?*
Pupil:	*We calculated the circumference of the circle and time taken to find velocity. The substituted it in the equation for angular velocity.*
Pupil:	*We substituted the given values, rearranged the equations and found angular velocity*
Teacher:	*Did you face any difficulty in any stage?*
Pupil:	*Only in the beginning stage*

Step 3. Analogical Problem Solving

Teacher: *Now you have to solve the following problem going through all the steps we practiced today.*

(Teacher writes the analogical question on the black board)

An insect trapped in a circular groove of radius 12cm moves along the groove steadily and completes 7 revolutions in 100s. What is the angular speed of the insect?

(Students workout the problem individually or in small groups and report to the teacher)

Lesson 16: Horizontal Range of a Projectile

Name of teacher	:	Shareeja Ali M C
Class	:	11
Topic	:	Motion in a Plane
Time	:	1 hour

Objectives: To enable students to

- Draw a schematic diagram representing a given problem situation
- Identify different physical quantities given in a story problem
- Convert physical quantities in different units to SI units
- Select appropriate equations to solve a problem
- Compute horizontal range of a projectile using equations of motion in vertical and horizontal directions seperately

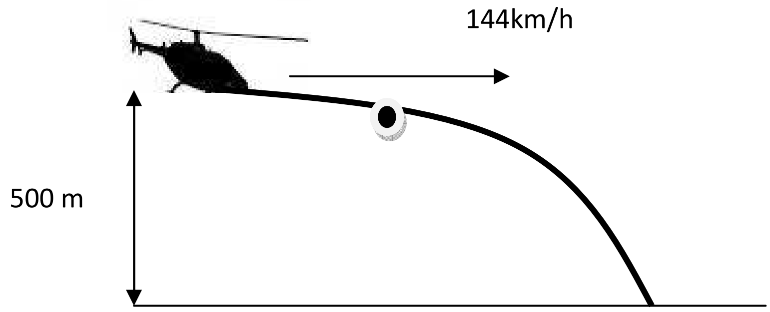
Resources: Concept map, diagrams

Phase 2: Presentation of the Problem

Teacher:	*A helicopter 500m high is flying horizontally with a speed of 144km/h. It drops a food packet. How far should a boy just below the helicopter run to get the food packet?*

Phase 3: Problem solving procedure.

Step 1: Surface representation



Step 2: Structure Representation

Teacher:	*Let us discuss the motion of the projected food packet in the horizontal and vertical direction. What is the initial horizontal velocity of the projected food packet?*
Pupil:	*144km/h*
Teacher:	*What is its initial vertical velocity?*
Pupil:	*Zero*
Teacher:	*What is the horizontal distance covered?*
Pupil:	*Unknown. It is to be determined.*
Teacher:	*What is the vertical distance covered?*
Pupil:	*500m*
Teacher:	*What is the horizontal acceleration?*
Pupil:	*Zero*
Teacher:	*What is the vertical acceleration?*
Pupil:	$9.8\ m/s^2$

Step 3: Planning the solution

Teacher:	*Let us now plan which equation can we use and how can we solve the problem.*
Pupil:	*Yes*
Teacher:	*What are the known horizontal physical quantities?*
Pupil:	*Initial velocity and acceleration*
Teacher:	*Can we find distance travelled using,* $S=ut + ½ at^2$*?*
Pupil:	*No, because we do not know time.*
Teacher:	*What are the vertical physical quantities known?*
Pupil:	*Initial velocity, distance and acceleration*
Teacher:	*Can we find time using these quantities?*
Pupil:	*Yes, using* $S = ut + ½ at^2$
Teacher:	*Are all the quantities in SI?*
Pupil:	*No. Initial horizontal velocity is in km/h*
Teacher:	*Then convert it in to m/s*
Pupil:	(Work out in their note books. Teacher offers help to some students) $144km/h = 144×1000/60×60\ m/s$ $=40\ m/s$

Step 4: Implementing the plan

Teacher:	*Now we can proceed according to our plan.*
	(Teacher work out on the black board)
	To find time, substituting the vertical quantities in equation,
	$S= ut + ½ at^2$
	$500 = 0 + ½ \times 9.8t^2$
	$500 = 4.6t^2$
	Rearranging
	$t^2 = 500/4.6$
	$=108.7$
	Therefore, $t =10.42$ *seconds*
	To find horizontal distance covered, substituting horizontal quantities in equation,
	$S = ut + ½ at^2$
	$= 40\times 10.4^2 + ½ \times 0\times (10.42)^2$
	$=417.03\ m$

Phase 4: Metacognitive Analysis

Step 1: Error Analysis

Teacher:	*The equation we used is,*
	$S = ut + ½ at^2$
	Write the units used for each of the quantities and see whether they are the same for each term on either side of the equation.
Pupil:	(work out in their books)
	$S = ut + ½ at^2$
	$m =m/s \times s + m/s^2\times s^2$
	$m= m +m$
	The units for all the terms are the same.
Teacher:	*Therefore the equation is consistent unit wise.*

Step 2: Monitoring the Procedure

Teacher:	*What was your first step while solving the problem?*
Pupil:	*We drew the diagram showing a helicopter dropping a food packet and marked its initial velocity, and height from the ground*
Teacher:	*What were the physical quantities given directly?*
Pupil:	*Initial horizontal velocity and vertical distance covered.*
Teacher:	*Which physical quantities were to be determined?*
Pupil:	*horizontal distance covered by the projectile*
Teacher:	*What physical quantities did you assume?*
Pupil:	*We assumed initial vertical velocity as zero, vertical acceleration as 9.8, and horizontal acceleration as zero*
Teacher:	*Which equation did you use?*
Pupil:	*We used* $S= ut + ½ at^2$*, in vertical and horizontal directions seperately*
Teacher:	*were all the equations given in SI?*
Pupil:	*No*
Teacher:	*What unit conversions did you make?*
Pupil:	*We converted km/h to m/s*
Teacher:	*How did you solve the problem?*
Pupil:	*We substituted the vertical values in* $S= ut + ½ at^2$ *and found time. Then we substituted the horizontal quantities in the same equation and found the horizontal range.*
Teacher:	*Did you face any difficulty in any stage?*
Pupil:	*In the planning stage. But now it is clear.*

Step 3. Analogical Problem Solving

Teacher:	*Now you have to solve the following problem going through all the steps we practiced today.* (Teacher writes the analogical question on the black board) *An aeroplane is flying in a horizontal direction with a velocity of 360km/h at a height of 1960m. How far from a given target, should it release a bomb to hit the target?*

(Students workout the problem individually or in small groups and report to the teacher)

Lesson 17: Time of Flight of a Projectile

Name of teacher	: Shareeja Ali M C
Class	: 11
Topic	: Motion in a Plane
Time	: 1 hour

Objectives: To enable students to

- Draw a schematic diagram representing a given problem situation
- Identify different physical quantities given in a story problem
- Select appropriate equations to solve a problem
- Compute time of flight of a projectile from equations of motion in two dimensions

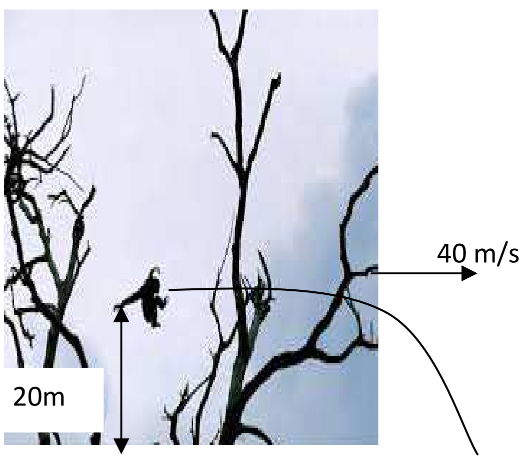
Resources : Concept map, diagrams

Phase 2: Presentation of the Problem

Teacher: *A monkey jumps from the branch of a tree 20m high from the ground with a horizontal velocity of 40m/s. How long will it stay in air?*

Phase 3: Problem solving procedure.

Step 1: Surface representation



Step 2: Structure Representation

Teacher:	*Let us discuss the motion of the monkey in the horizontal and vertical directions. What is the horizontal velocity of the monkey?*
Pupil:	*40 m/s*
Teacher:	*What is the initial vertical velocity of the monkey?*
Pupil:	*Zero*
Teacher:	*What is the horizontal distance travelled by the monkey?*
Pupil:	*Unknown*
Teacher:	*What is the vertical distance travelled by the monkey?*
Pupil:	*20m*
Teacher:	*What is the horizontal acceleration?*
Pupil:	*Zero*
Teacher:	*What is the vertical acceleration?*
Pupil:	*9.8* m/s^2
Teacher:	*What is to be determined?*
Pupil:	*Time of flight of the monkey*

Step 3: Planning the solution

Teacher:	*Let us now plan what equations can be used and how we can solve the problem.*
Pupil:	*Yes*
Teacher:	*Which horizontal physical quantities are known?*
Pupil:	*Initial velocity and acceleration*
Teacher:	*which vertical physical quantities are known?*
Pupil:	*Initial velocity, acceleration and distance.*
Teacher:	*which equation can be used to find time?*
Pupil:	$S = ut + ½ at^2$ *in vertical*
Teacher:	*Why can't we use it in horizontal direction?*
Pupil:	*horizontal distance covered by the monkey is not known*
Teacher:	*Are all the units in SI system?*
Pupil:	*Yes*
Teacher:	*So, do we have to make unit conversions?*
Pupil:	*No*

Step 4: Implementing the plan

Teacher:	*Now we can proceed according to our plan.* (Teacher work out on the black board) *Substituting the values in equation,* $S = ut + \frac{1}{2} at^2$ $20 = 0 + \frac{1}{2} \times 9.8 \times t^2$ $20 = 4.9t^2$ Rearranging $t^2 = 20/4.9$ $=4.08$ *Therefore,* $t = 2.02$ *seconds*

Phase 4: Metacognitive Analysis

Step 1: Error Analysis

Teacher:	*The equation we used is,* $S = ut + \frac{1}{2} at^2$ *Write the units used for each of the quantities and see whether they are the same for each term on either side of the equation.*
Pupil:	(work out in their books) $S = ut + \frac{1}{2} at^2$ $m = m/s \times s + m/s^2 \times s^2$ $m = m + m$ *The units for all the terms are the same.*
Teacher:	*Therefore the equation is consistent unit wise.*

Step 2: Monitoring the Procedure

Teacher:	*What was your first step while solving the problem?*
Pupil:	*We drew a diagram showing a monkey jumping from a tree and we marked its initial velocity and height of the tree*
Teacher:	*Which physical quantities were given directly?*
Pupil:	*Initial horizontal velocity of the monkey and vertical distance covered by the monkey*
Teacher:	*Which physical quantities were to be determined?*
Pupil:	*Time of flight of the monkey*
Teacher:	*Which equations were used?*

Pupil:	*$S = ut + ½ at^2$*
Teacher:	*What assumptions did we make?*
Pupil:	*We assumed that the vertical acceleration is 9.8 and that the initial vertical velocity is zero*
Teacher:	*Did you face any difficulty in any stage?*
Pupil:	*No*

<u>Step 3. Analogical Problem Solving</u>

Teacher:	*Now you have to solve the following problem going through all the steps we practiced today.* (Teacher writes the analogical question on the black board) *A bird flying at a height of 60m with a horizontal speed of 50m/s drops a fish in its mouth. How long will it take the fish to reach the ground?*

(Students workout the problem individually or in small groups and report to the teacher)

Lesson 18: Time for Upward and Downward Motion

Name of teacher: Shareeja Ali M C
Class : 11
Topic : Motion in a Plane
Time : 1 hour

Objectives: To enable students to

- Draw a schematic diagram representing a given problem situation
- Identify different physical quantities given in a story problem
- Select appropriate equations to solve a problem
- Estimate the time for upward and downward motion using equations of motion

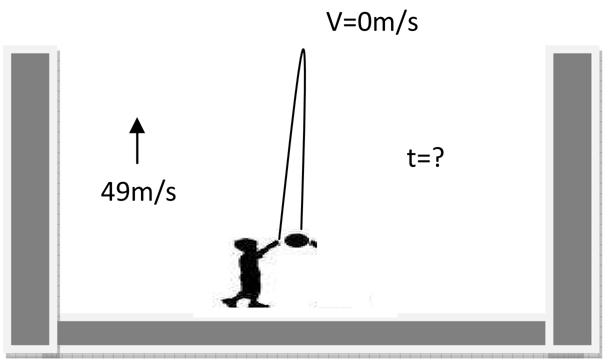
Resources: Concept map, diagrams

Phase 2: Presentation of the Problem

Teacher:	*A boy is playing with a ball in a train moving with a speed of 100km/h. If he throws the ball up with a speed of 10m/s. How long will the ball stay in air before reaching his hands?*

Phase 3: Problem solving procedure.

Step 1: Surface representation



Step 2: Structure Representation

Teacher:	*Let us discuss the case of a ball moving upwards. When the ball moves upwards, what happens to its velocity? Does it increase or decrease?*
Pupil:	*Decreases*
Teacher:	*So, is its acceleration positive or negative?*
Pupil:	*negative*
Teacher:	*What will be the magnitude of acceleration?*
Pupil:	*9.8* m/s^2
Teacher:	*Why is it 9.8* m/s^2
Pupil:	*the ball is accelerated by gravity*
Teacher:	*So, we can take the acceleration,* $a = -9.8\ m/s^2$ *At the topmost point the ball remains stationary for a fraction of a second and comes back. So what will be the final velocity for upward motion?*
Pupil:	*Zero*
Teacher:	*Yes, so we can take final velocity,* $v=0m/s$

Step 3: Planning the solution

Teacher:	*Let us now plan which equation can we use and how can we solve the problem.*
Pupil:	*Yes*
Teacher:	*Which physical quantities are known?*
Pupil:	*We know, initial velocity, final velocity, and acceleration.*
Teacher:	*What is to be determined?*
Pupil:	*Time*
Teacher:	*So which equation can we use to solve this problem?*
Pupil:	$v = u + at$
Teacher:	*this will give us only the time for upward motion. But the time taken for upward motion will be same as the time taken for downward motion. Can you guess how to find the total time taken by the boy to return to the boy's hand?*
Pupil:	*We will just have to take twice the time for upward motion*
Teacher:	*Yes. Good.*
Teacher:	*Are all the units in SI system?*
Pupil:	*Yes*

Step 4: Implementing the plan

Teacher:	*Now we can proceed according to our plan.* (Teacher work out on the black board) *Substituting the values in equation,* $v = u + at$ $0 = 49 - 9.8 \times t$ Rearranging $9.8 \times t = 49$ $t = 49/9.8$ $= 5$ *seconds* *This is the time for upward motion. So the total time taken by the ball to fall back to the boy's hand is twice this time.* $2 \times 5 = 10$ *seconds*

Phase 4: Metacognitive Analysis

Step 1: Error Analysis

Teacher:	*The equation we used is,* $v = u + at$ *Write the units used for each of the quantities and see whether they are the same for each term on either side of the equation.*
Pupil:	(work out in their books) $v = u + at$ $m/s = m/s + m/s^2 \times s$ $m/s = m/s + m/s$ *The units for all the terms are the same.*
Teacher:	*Therefore the equation is consistent unit wise.*

Step 2: Monitoring the Procedure

Teacher:	*What was your first step while solving the problem?*
Pupil:	*We drew a diagram showing the boy throwing the ball upwards and marked the initial velocity and velocity at the top.*
Teacher:	*Which physical quantities were given directly?*
Pupil:	*Only initial velocity*
Teacher:	*Which physical quantities were to be determined?*
Pupil:	*Time*
Teacher:	*Which physical quantities did you assume?*
Pupil:	*We assumed velocity of the ball at the topmost point as zero, and the acceleration on the ball as -9.8* m/s^2
Teacher:	*What other assumption did you make?*
Pupil:	*We assumed that time for upward motion is equal to time for downward motion*
Teacher:	*Where all the quantities in SI unit?*
Pupil:	*yes*
Teacher:	*How did you solve the problem?*
Pupil:	*We substituted the given values, rearranged the equations and found time and took twice its valu.*
Teacher:	*Did you face any difficulty in any stage?*
Pupil:	*No*

Step 3. Analogical Problem Solving

Teacher:	*Now you have to solve the following problem going through all the steps we practiced today.* (Teacher writes the analogical question on the black board) *A basket ball player throws up the ball with a speed of 20 m/s as he runs with a speed of 30m/s. In what time will the ball reach back to his hands?*

(Students workout the problem individually or in small groups and report to the teacher)

Lesson 19: Variation in Velocity of a Projectile

Name of teacher	: Shareeja Ali M C
Class	: 11
Topic	: Motion in a Plane
Time	: 1 hour

Objectives: To enable students to

- Draw a schematic diagram representing a given problem situation
- Identify different physical quantities given in a story problem
- Describe the variation in horizontal and vertical velocities of a projectile
- Estimate the velocity of a projectile at its highest point

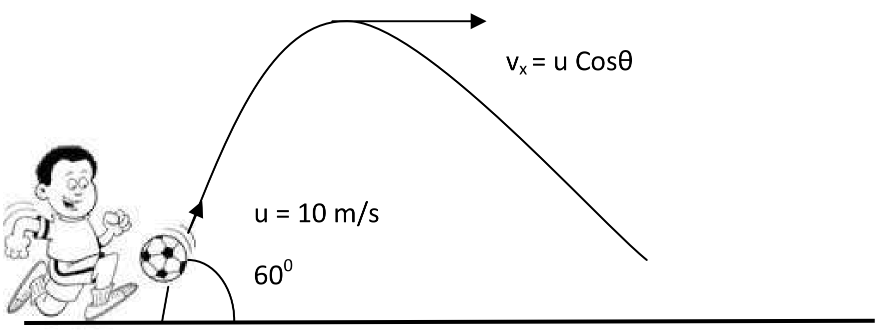
Resources : Concept map, diagrams

Phase 2: Presentation of the Problem

Teacher: *A ball is kicked with a velocity of 10m/s at an angle of 60^0 with the horizontal. What is its velocity at the highest point?*

Phase 3: Problem solving procedure.

Step 1: Surface representation



Step 2: Structure Representation

Teacher:	*Let us discuss the projectile motion of the ball. What is the initial velocity of the ball?*
Pupil:	*10m/s*
Teacher:	*What is the angle made by the ball when it is projected?*
Pupil:	60^0
Teacher:	*So we can resolve the initial velocity in to horizontal and vertical components*
Pupil:	*Yes*
Teacher:	*What is the horizontal component of initial velocity,* u_x*?*
Pupil:	$u_x = u \, Cos\, \theta$ (Looking at the concept map)
Teacher:	*What is the vertical component of initial velocity,* u_y*?*
Pupil:	$u_y = u \, Sin\theta$ (Looking at the concept map)

Step 3: Planning the solution

Teacher:	*Let us now plan how we can solve the problem.*
Pupil:	*Yes*
Teacher:	*As the ball goes up, what happens to its horizontal velocity? Will it change?*
Pupil:	*No*
Teacher:	*So even at the topmost point, it will be same as the initial velocity?*
Pupil:	*Yes*
Teacher:	*Then how much is the horizontal component of velocity at the topmost point?*
Pupil:	$u \, Cos\, \theta$
Teacher:	*What happens to the vertical component of velocity as the ball goes up?*
Pupil:	*Decreases*
Teacher:	*Why does the vertical component of velocity decrease?*
Pupil:	*Because there is gravity pulling it down*
Teacher:	*Very good. Then what will be the ball's vertical component of velocity at the topmost point?*
Pupil:	*Zero*
Teacher:	*So we have to compute only the horizontal component of velocity at its topmost point.*
Pupil:	*Yes*

Step 4: Implementing the plan

Teacher:	*Now we can proceed according to our plan.* (Teacher work out on the black board) *Substituting the values in equation,* *At the topmost point,* $v = u\ Cos\theta$ $= 10 \times Cos\ 60$ $=5\ m/s$

Phase 4: Metacognitive Analysis

Step 1: Error Analysis

Teacher:	*We used the equation* $v=u\ Cos\ \theta$ *Write the units used for each of the quantities and see whether they are the same for each term on either side of the equation.*
Pupil:	(work out in their books) $v = u\ Cos\ \theta$ $m/s = m/s$ *The units for all the terms are the same.*
Teacher:	*Therefore the equation is consistent unit wise.*

Step 2: Monitoring the Procedure

Teacher:	*What was your first step while solving the problem?*
Pupil:	*We drew a diagram showing a boy kicking a ball and drew the path of the ball. We marked its angle with the horizontal and initial velocity.*
Teacher:	*Which physical quantities were given directly?*
Pupil:	*Initial velocity of the ball and angle of projection*
Teacher:	*Which physical quantities were to be determined?*
Pupil:	*The velocity of the ball at its highest point*
Teacher:	*Which equations were used?*
Pupil:	$v =u\ Cos\ \theta$
Teacher:	*Did you make any unit conversions*
Pupil:	*No*
Teacher:	*what assumptions did you make?*
Pupil:	*We assumed that the vertical velocity at the highest point is zero*
Teacher:	*Did you face any difficulty in any stage?*
Pupil:	*No*

Step 3. Analogical Problem Solving

Teacher:	*Now you have to solve the following problem going through all the steps we practiced today.* (Teacher writes the analogical question on the black board) *A stone is thrown with a velocity of 15m/s at an angle of 30^0 with the horizontal. What are its horizontal and vertical components of velocity at its highest point?*

(Students workout the problem individually or in small groups and report to the teacher)

Lesson 20: The Maximum Height of a Projectile and Horizontal Range

Name of teacher	:	Shareeja Ali M C
Class	:	11
Topic	:	Motion in a Plane
Time	:	1 hour

Objectives: To enable students to

- Draw a schematic diagram representing a given problem situation
- Identify different physical quantities given in a story problem
- Select appropriate equations to solve a problem
- To estimate the horizontal range within a maximum possible height of the projectile

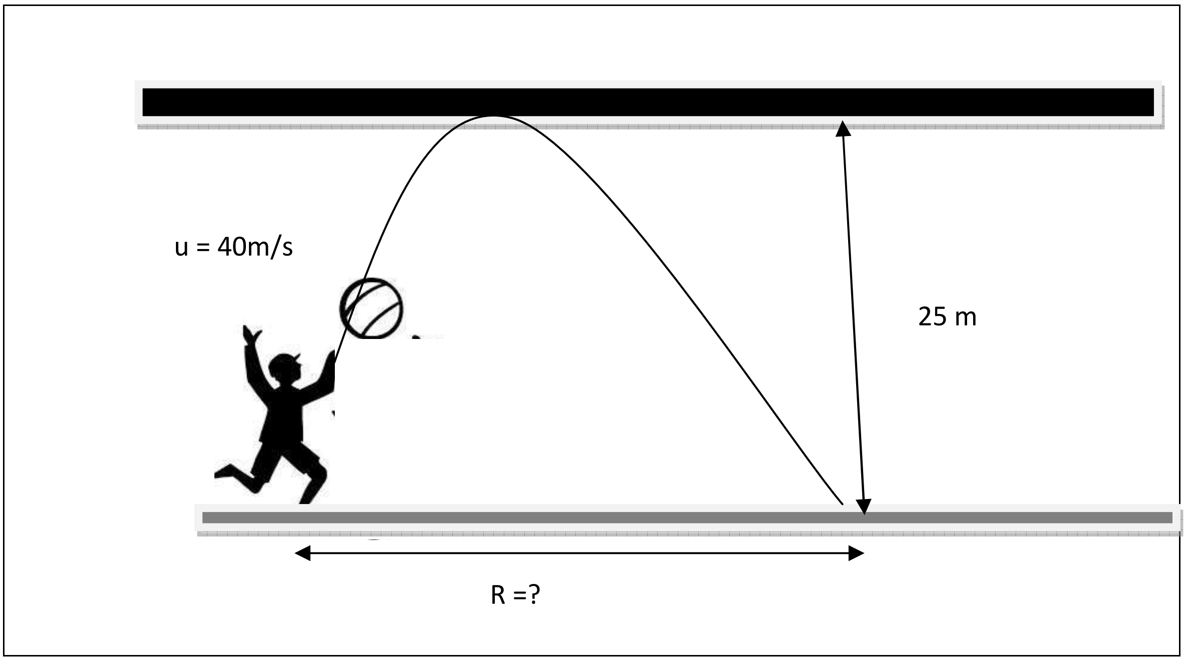
Resources: Concept map, diagrams

Phase 2: Presentation of the Problem

Teacher:	*The ceiling of a roof is 25m high. What is the maximum distance that a ball thrown at a speed 40m/s can go without hitting the roof?*

Phase 3: Problem solving procedure.

Step 1: Surface representation



Step 2: Structure Representation

Teacher:	*Let us discuss how we can throw the ball to reach the maximum range for a particular height*
Pupil:	*Yes*
Teacher:	*What is the angle of projection for maximum horizontal range?*
Pupil:	45^0
Teacher:	*What is initial velocity given in the problem?*
Pupil:	*40 m/s*
Teacher:	*What is the equation for the height of the projectile?*
Pupil:	$H= u^2 Sin^2\theta / 2g$ *(Looking in to the concept map)*
Teacher:	*What is the maximum possible height the projectile can go in this problem?*
Pupil:	*25 meters*

Step 3: Planning the solution

Teacher:	*See whether the ball goes beyond this height, if we throw the ball with an initial velocity of 40 m/s at* 45^0
Pupil:	(Work out in their note books. Teacher offers help to some students) $H = u^2 Sin^2\theta /2g$ $= (40)^2 (Sin\ 45)^2 / 2\times9.8$ $=40.81\ m$
	The ball will go to a height above 25 meters
Teacher:	*So we cannot project it at an angle of* 45^0 *Now, how can we find the angle of projection for a height of 25m.*
Pupil:	*By putting H=25m in the equation for height*
Teacher:	*Ok. Thus we will get θ. What is the equation to find horizontal range?*
Pupil:	$R = u^2 Sin2\theta /g$ (Looking at the concept map)
Teacher:	*Other than θ, what is required to find R?*
Pupil:	*Initial velocity, u. It is given in the question.*
Teacher:	*Is it in SI unit?*
Pupil:	*Yes*

Step 4: Implementing the plan

Teacher:	*Now we can proceed according to our plan to solve the problem.* (Teacher work out on the black board) *To find θ, substituting the values of height and initial velocity in the equation,* $H = u^2 Sin^2\theta /2g$ $25 = (40)^2 Sin^2\theta / 2\times9.8$ Rearranging $Sin^2\theta = 2\times9.8\times25/1600$ $= 0.306$ *Therefore,* $Sin\theta = 0.55$ *Therefore,* $\theta = 33^0$ *To find the maximum possible horizontal range, substituting values of initial velocity and angle of projection in the second equation* $R = u^2 Sin2\theta/g$ $= (40)^2 (Sin\ 66)/ 9.8$ $= 149m$

Phase 4: Metacognitive Analysis

Step 1: Error Analysis

Teacher:	*The equation we used was,* $H = u^2 Sin^2\theta /2g$ *Write the units used for each of the quantities and see whether they are the same for each term on either side of the equation.*
Pupil:	(work out in their books) $H = u^2 Sin^2\theta /2g$ $m =(m/s)^2/(m/s^2)$ $m=m$ *The units for all the terms are the same.*
Teacher:	*Therefore the equation is consistent unit wise.* *We also used the equation,* $R = u^2 Sin2\theta/g$ *Write the units used for each of the quantities and see whether they are the same for each term on either side of the equation.*
Pupil:	(work out in their books) $R = u^2 Sin2\theta/g$ $m = (m/s)^2/(m/s^2)$

	m=m
	The units for all the terms are the same.
Teacher:	*Therefore the equation is unit wise consistent*

Step 2: Monitoring the Procedure

Teacher:	*What was your first step while solving the problem?*
Pupil:	*We drew a diagram showing a boy throwing a ball inside a room and marked the maximum possible height*
Teacher:	*Were the physical quantities given directly?*
Pupil:	*No. We had to find the angle of projection possible.*
Teacher:	*Which physical quantities were to be determined?*
Pupil:	*The maximum possible range within the given height*
Teacher:	*Which equation did you use?*
Pupil:	*We used two equations,* $H = u^2 \, Sin^2\theta /2g$ *and* $R = u^2 \, Sin2\theta/g$
Teacher:	*were all the quantities given in SI?*
Pupil:	*Yes*
Teacher:	*How did you solve the problem?*
Pupil:	*We substituted the given values, checked the possibilities of height, rearranged the equations and found maximum possible horizontal range for the given height.*
Teacher:	*Did you face any difficulty in any stage?*
Pupil:	*Yes in the planning and implementing stage. But now the strategy is clear.*

Step 3. Analogical Problem Solving

Teacher:	*Now you have to solve the following problem going through all the steps we practiced today.* (Teacher writes the analogical question on the black board) *A boy kicks a football with a speed of 50m/s. If it reaches a height of 15 m from the ground, what will be the distance covered by the ball as it touches the ground?*

(Students workout the problem individually or in small groups and report to the teacher)

Lesson 21: Newton's Laws of Motion

Name of teacher:		Shareeja Ali M C
Class	:	11
Unit	:	Laws of Motion
Time	:	1 hour

Objectives: To enable students to

- Describe what force does
- State Newton's first law
- State Newton's second law
- Compute force
- Apply conservation of momentum
- Define weight
- Describe the situation of weightlessness
- Compare apparent weight when an elevator moves up and down

Resources: Concept map, catapult, bouncing ball

Phase 1: Presentation of Knowledge domain.

(The concept map for the unit, 'Laws of Motion' developed during the lesson is shown in figure.)

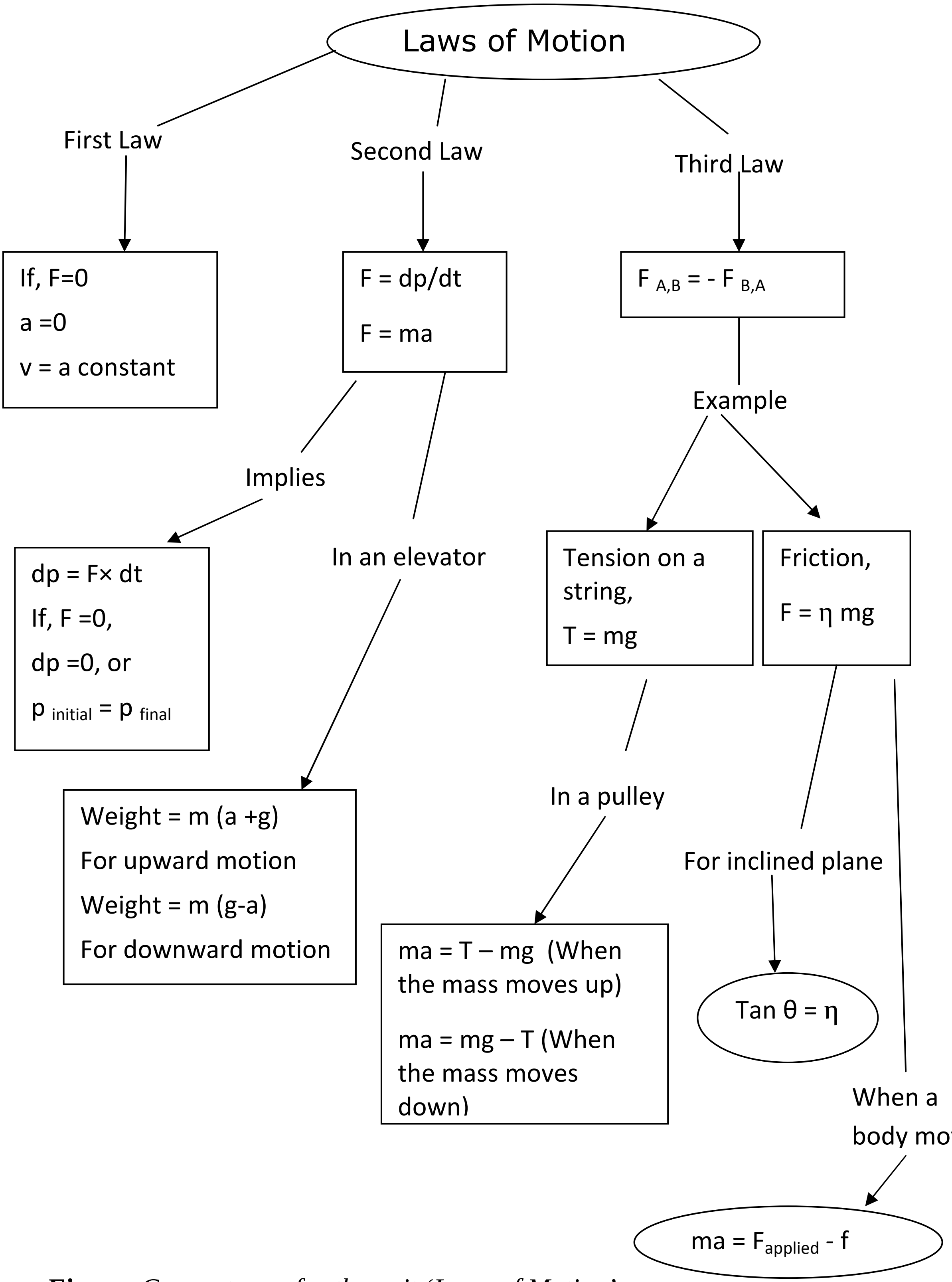


Figure: *Concept map for the unit 'Laws of Motion'*

Teacher:	*We have learned about motion and solved many problems related to motion in one and two dimensions. Today we can learn some general laws put forward by Sir Isaac Newton. These laws have far reaching consequences in our everyday life.* *Suppose you want to move your table nearer to you. What will you do?*
Pupil:	*Pull it*
Teacher:	(Rolls a ball towards the pupil and asks) *If a ball comes towards you. What will you do to stop it?*
Pupil:	*Push it*
Teacher:	*Such pushes and pulls are called force. So you can make a body move, or come to rest by applying force. Suppose a ball is rolling on a floor. What will happen to it after some time?* (Teacher rolls the ball on the floor)
Pupil:	*It will stop*
Teacher:	*It stops due to friction. Friction is a type of force. What will happen if there is no friction?*
Pupil:	*The ball will continue rolling*
Teacher:	*So a body will continue its motion if there is no force on it.* *Let me summaries. A force is required to stop motion and also to start motion. If there is no force the body will continue to remain in rest or in uniform motion. This is Newton's first law.* *What will be the acceleration of a body at rest?*
Pupil:	*Zero*
Teacher:	*What will be the acceleration of a body making uniform motion?*
Pupil:	*Zero*
Teacher:	*So , we can state Newton's first law mathematically as,* *If* , $F = 0$ $a = 0$, *or* v = *a constant* *while Newton's first law states why we need force, Newton's second law gives the amount of force.* *Let me discuss two situations* *1. I throw a bullet at a wall* *2. I fire a bullet with a gun at a wall* *In which of these situations the force will be more?*
Pupil:	*When you fire a bullet with a gun*
Teacher:	*Why?*

Pupil:	*The bullet is moving faster*
Teacher:	*Let me discuss other two situations with you* *1. I throw a stone weighing 2kg at a wall* *2. I throw a stone weighing ½ kg at a wall* *In which of these situations the force will be more?*
Pupil:	*When you throw 2 kg stone at the wall*
Teacher:	*Why?*
Pupil:	*It has more mass.*
Teacher:	*So if there is more mass and more velocity, the force on the wall will be more.* *Product of mass and velocity is called momentum* $p = mv$ *When the stone or bullet hits the wall, its velocity changes to zero. Newtons' second law states that force is rate of change of momentum.* $F = dp/dt$, *Where dp is change in momentum.* $dp = p_{final} - p_{initial}$ *Can you calculate the force experienced by a person when he catches a ball of mass, 0.5kgcomming with a speed of 10m/s in 2 seconds.*
Pupil:	(Workout in their note books. Teacher offers help to some students) $F = dp/dt$ $= (0.5\times10)/2$ $=2.5\ N$
Teacher:	*Correct. What will happen if there is no force? Will the momentum change?*
Pupil:	*No*
Teacher:	*In that case initial momentum will be equal to final momentum.* $p_{initial}= p_{final}$ *Suppose a gun weighing 2kg fires a bullet of 50g with a speed of 500m/s. Can you find the velocity with which the gun recoils?*
Pupil:	*Confused*
Teacher:	*Is the gun moving before it fires?*
Pupil:	*No*
Teacher:	*So its velocity is zero. What about its momentum?*
Pupil:	*Zero*

Teacher:	*So before firing, the total momentum is zero, or* $p_{initial} = 0$.
	After firing what will be the momentum of the bullet? Don't forget to convert 50g into kg.
Pupil:	(Workout in their note book)
	$50g = 50/1000\ kg$
	$= 0.05\ kg$
	$p = mv$
	$= 0.05 \times 500$
	$= 25 kg\ m/s$
Teacher:	*Very good. Now the total final momentum will be*
	Recoil momentum of the gun- momentum of the bullet
	It will be zero, because initial momentum is zero, and
	$p_{initial} = p_{final}$
	So, momentum of the gun = momentum of the bullet
	Now, can you calculate recoil velocity?
Pupil:	*(Work out in their books. Teacher offers help to some students)*
	$v \times 2 = 25$
	Therefore, $v = 25/2$
	$= 12.5\ m/s$
Teacher:	*Correct.*
	(Teacher summarizes the topics covered, completes the concept map and asks some assessment questions)
Teacher:	*Give few situations where force is applied*
	State Newton's first law
	State Newton's second law

Lesson 22: Newton's Third Law

Name of teacher:		Shareeja Ali M C
Class	:	11
Topic	:	Laws of motion
Time	:	1 hour

Objectives: To enable students to

- State Newton's third law
- Identify reaction forces like friction and tension on a string
- Compute angle of inclination when a body just begins to slide on an inclined plane
- Describe the relation between forces when a body moves on a pulley

Resources: Concept map, diagrams, ball

Phase 1: Presentation of the knowledge domain

(Teacher refreshes the topics covered in the previous lesson while retracing the concept map already drawn)

Teacher:	*We have learned Newton's first and second laws in the previous classes. Today, let us learn Newton's third law and some of its consequences.* *Have you played with a rubber ball?*
Pupil:	Yes
Teacher:	*What will happen if you strike it on the ground?*
Pupil:	*It bounces*
Teacher:	*Why does it bounce?*
Pupil:	*We do not know*
Teacher:	*When you strike ball on the ground, ball applies a force on the ground. The ground applies an equal force back on the ball.* *What will happen if you strike the ball harder?*
Pupil:	*It bounce higher, because the ground pushes it harder.*
Teacher:	*Good* *So, if you increase the force on the ground, the ground will also increase the force on the ball. This is explained by Newton's third law.* *It states that for every action, there is an equal and opposite reaction.* *Here action and reaction refers to forces. Mathematically it can be written as,* $F_{AB} = - F_{BA}$

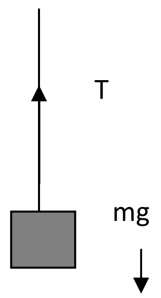
	F_{AB} *is force experienced by A due to B*
	F_{BA} *is force experienced by B due to A*
Teacher:	*Can you give examples or situations of Newton's third law?*
Pupil:	*Bow and arrow*
Teacher:	*Yes, when you pull the bow with an arrow, the bow pushes the arrow in the opposite direction. Can you tell another example?*
Pupil:	*Rocket propulsion*
Teacher:	*Correct, when the exhaust gas comes down, the rocket goes up. Let me repeat a question asked in the last class. What will happen to a rolling ball after some time?*
Pupil:	*It stops due to friction*
Teacher:	*Friction is a reaction force acting on moving bodies. When a ball moves forward, reaction force or friction force opposes it. Where will be more friction, on a rough plane or a smooth plane?*
Pupil:	*Rough plane*
Teacher:	*Correct. Different surfaces have different amount of friction. They are characterized by a coefficient of friction, η. The frictional force on a body of mass 'm' is* $f = \eta mg$ *Can you calculate the frictional force on a car weighing 200kg on a road of coefficient of friction 0.3?*
Pupil:	(Workout in their note book. Teacher offers guidance to some students) $F = \eta mg$ $= 0.3 \times 200 \times 9.8$ $= 588N$
Teacher:	*Correct. If its engine applies a force,* $F_a = 700N$ *on the car, can you calculate the resultant force on the car?*
Pupil:	(Workout in their note book. Teacher offers guidance to some students) $F = F_a - f$ (Looking at the concept map) $=700 - 588$ $=112N$
Teacher:	*Good. Can you calculate the acceleration of the car?*
Pupil:	(Workout in their note book. Teacher offers guidance to some students) $F = ma$ Therefore, $a = F/m$ $= 112/200$ $=0.56\ m/s^2$
Teacher:	*Excellent.* *Some times a body starts moving even if we do not apply force with our hands. Example is an inclined plane. When a body just starts sliding,*

Tan θ = η

Where θ is the angle of inclination

	Keep your eraser on your notebook and raise one side of the note book slowly, till the eraser just start moving and find the coefficient of friction between the surface of the note book and the eraser.
Pupil:	(Does as the teacher says. Measures θ with a protractor and calculate η in their note book)
Teacher:	*Correct.*
	Suppose we tie a body on a string and hang it. If the body is too heavy for the string, what will happen to the string?
Pupil:	*It will break*
Teacher:	*Correct.*
	Have you thought what is called weight? It is gravitational force on a body. So by Newton's second law,

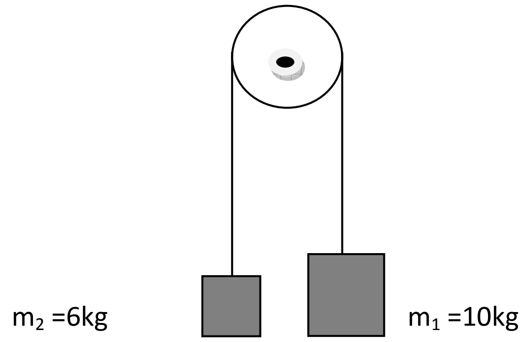
Weight = mg



	When we hang a body on a string, mg acts downwards and an equal tension force acts upwards.
	Suppose a body of 2kg mass is hung on a string, calculate the tension on the string.
Pupil:	(Workout in their note book. Teacher offers guidance to some students)

$$T = mg$$
$$= 2\times 9.8$$
$$= 19.6\ N$$

Teacher:	*Correct. Suppose, there are two masses on a pulley, m_1 and m_2*



Which of these will move up and which will move down?

Pupil: *10kg moves down and 6kg moves up*

Teacher: *As they move together, both moves with the same acceleration. When one moves up, ma acts in the same direction as T, but mg acts downwards. So in this case,*

$$m_2a + T = m_2g$$

or

$$m_2a = m_2g - T$$

If the body moves down, both ma and mg are downwards and T is upwards.

$$m_1a + m_1g = T$$

or

$$m_1a = T - m_1g$$

We will use these concepts while solving problems in next classes.

(Teacher summarizes the lesson and asks a few questions for reinforcement)

1. *State Newton's third law.*
2. *Identify reaction forces like friction and tension on a string.*
3. *Give the equation connecting angle of inclination and coefficient of friction.*
4. *What is weight?*

(Teacher completes the concept map and asks students to understand and copy that in their note books)

Lesson 23: Estimating Acceleration Using Newton's Second Law

Name of teacher: Shareeja Ali M C
Class : 11
Unit : Laws of Motion
Time : 1 hour

Objectives: To enable students to

- Draw a schematic diagram representing a given problem situation
- Identify different physical quantities given in a story problem
- Select appropriate equations to solve a problem
- Estimate acceleration using Newton's second law

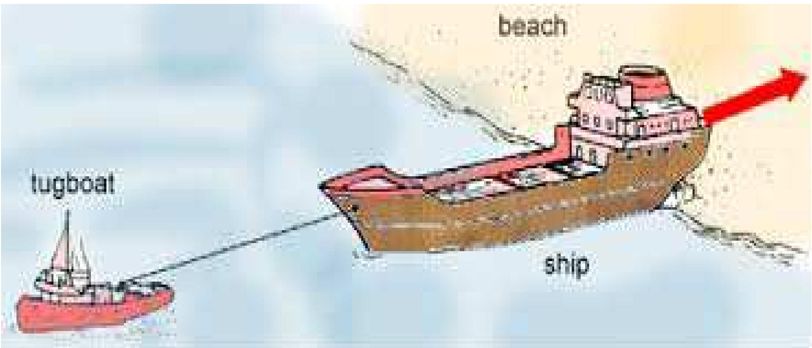
Resources: Concept map, diagrams

Phase 2: Presentation of the Problem

Teacher: *A boat of mass 3×10^7 kg initially at rest is pulled by a ship with a force of 6×10^4N. Calculate the acceleration attained by the boat.*

Phase 3: Problem solving procedure.

Step 1: Surface representation



F = 6×10^4 N

m = 3×10^7kg

Step 2: Structure Representation

Teacher:	*Let us discuss the motion of the boat. What is the mass of the boat?*
Pupil:	3×10^7 *kg*
Teacher:	*What is the force acting on it?*
Pupil:	6×10^4 *N*
Teacher:	*What is to be determined?*
Pupil:	*Acceleration*
Teacher:	*Are all the quantities in SI unit?*
Pupil:	*Yes*

Step 3: Planning the solution

Teacher:	*Let us now plan which equation can we use and how can we solve the problem.*
Pupil:	*Yes*
Teacher:	*Which are the known physical quantities?*
Pupil:	*We know mass of the boat and force on the boat.*
Teacher:	*What is to be determined?*
Pupil:	*acceleration of the boat*
Teacher:	*So which law can be used to solve this problem?*
Pupil:	*Newton's second law*
Teacher:	*What is the required equation?*
Pupil:	$F = ma$

Step 4: Implementing the plan

Teacher:	*Now we can proceed according to our plan.* *(Teacher work out on the black board)* *Substituting the values in equation,* $F = ma$ $6\times10^4 = 3\times10^7 \times a$ Therefore, $a = 6\times10^4 / 3\times10^7$ $=2\times10^{-3}\ m/s^2$

Phase 4: Metacognitive Analysis

Step 1: Error Analysis

Teacher:	*The equation we used is, F=ma* *Write the units used for each of the quantities and see whether they are the same for each term on either side of the equation. Note that newton is a derived SI unit. It can be written as kg* m/s^2
Pupil:	(work out in their books) $F = ma$ $N = kg\ m/s^2$ *The units for all the terms are the same.*
Teacher:	*Therefore the equation is consistent unit wise.*

Step 2: Monitoring the Procedure

Teacher:	*What was your first step while solving the problem?*
Pupil:	*We drew a diagram showing a ship pulling a tug boat of mass* 3×10^7 *kg with a force of* 6×10^4 *N*
Teacher:	*Which physical quantities were given directly?*
Pupil:	*Mass of the boat and force on the boat*
Teacher:	*Which physical quantities were to be determined?*
Pupil:	*Acceleration of the boat*
Teacher:	*How did you obtain the required relations?*
Pupil:	*We used Newton's second law*
Teacher:	*How did you solve the problem?*
Pupil:	*We substituted the given values, rearranged the equations and found acceleration*
Teacher:	*Did you face any difficulty in any stage?*
Pupil:	*No*

Step 3. Analogical Problem Solving

Teacher:	*Now you have to solve the following problem going through all the steps we practiced today.* (Teacher writes the analogical question on the black board) *A body of mass 12kg is moving with an acceleration of* $50m/s^2$. *Calculate the force acting on it.*

(Students workout the problem individually or in small groups and report to the teacher)

Lesson 24: Apparent Weight of Accelerated Bodies

Name of teacher: Shareeja Ali M C
Class : 11
Unit : Laws of motion
Time : 1 hour

Objectives: To enable students to

- Draw a schematic diagram representing a given problem situation
- Identify different physical quantities given in a story problem
- Select appropriate equations to solve a problem
- Estimate apparent weights of accelerated bodies

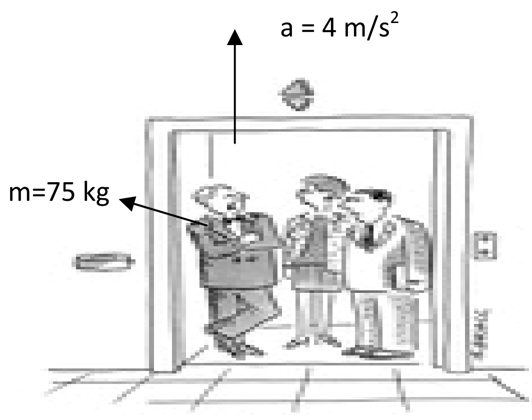
Resources: Concept map, diagrams

Phase 2: Presentation of the Problem

Teacher:	*A person weighting 75kg stands in an elevator. What will be the apparent weight of the man when the elevator moves up with an acceleration of 4 m/s²?*

Phase 3: Problem solving procedure.

Step 1: Surface representation



Step 2: Structure Representation

Teacher:	*Let us discuss the forces acting on a person and how we can calculate the apparent weight of accelerated bodies.* *Did you ever ride in a giant wheel?*
Pupil:	*Yes*
Teacher:	*What did you feel when you were moving down?*
Pupil:	*Weight less, light weight*
Teacher:	*You felt less than your actual weight?*
Pupil:	*Yes*
Teacher:	*This felt weight is called apparent weight.* *What is weight?*
Pupil:	*Gravitational force*
Teacher:	*How can you calculate it?*
Pupil:	*mg*
Teacher:	*Right. When you move down with an acceleration, a, your apparent weight* $W = mg - ma$ *That is why you feel lighter than your actual weight.* *What did you feel when you were going up on the giant wheel?*
Pupil:	*Very heavy*
Teacher:	*This is because your apparent weight is* $W = mg+ma$ *That is more than your actual weight.*

Step 3: Planning the solution

Teacher:	*Let us now plan which equation can we use and how can we solve the problem.*
Pupil:	*Yes*
Teacher:	*Which physical quantities are given?*
Pupil:	*Mass of the person and acceleration of the elevator*
Teacher:	*Is the elevator moving up or down?*
Pupil:	*It is moving up*
Teacher:	*Then which equation should we use to find apparent weight?*
Pupil:	$W = mg + ma$
Teacher:	*Correct. Are all the quantities given in SI unit?*
Pupil:	*Yes*
Teacher:	*What is the SI unit of weight?*
Pupil:	*Do not know*
Teacher:	*Weight is gravitational force. So its unit can be newton, kgwt, or kg* m/s^2

Step 4: Implementing the plan

Teacher:	*Now we can proceed according to our plan.* (Teacher work out on the black board) *To find apparent weight, substituting the values in equation,* $W = mg + ma$ $= 75\times9.8 + 75\times4$ $=735+300$ $=1035\ N$ $= 1035/9.8\ kgwt$ $=105\ kgwt$ *This is much more than his actual weight.*

Phase 4: Metacognitive Analysis

Step 1: Error Analysis

Teacher:	*The equation we used is, W = mg + ma* *Write the units used for each of the quantities and see whether they are the same for each term on either side of the equation.*
Pupil:	(work out in their books) $W = mg + ma$ $N = kg\ m/s^2 + kg\ m/s^2$ *The units for all the terms are the same.*
Teacher:	*Therefore the equation is consistent unit wise.*

Step 2: Monitoring the Procedure

Teacher:	*What was your first step while solving the problem?*
Pupil:	*We drew a diagram showing people in an elevator. Then we discussed the motion of people in a giant wheel.*
Teacher:	*In which case you will feel lighter than your actual weight?*
Pupil:	*When the giant wheel moves down*
Teacher:	*Then which equation will you use to find your apparent weight?*
Pupil:	$W = mg - ma$
Teacher:	*In which case will you feel heavier than your actual weight?*
Pupil:	*When the giant wheel goes up*
Teacher:	*Then which equation will you use to find the apparent weight?*
Pupil:	$W = mg + ma$

Teacher:	*Which physical quantities were given in the problem?*
Pupil:	*Mass of the person and acceleration of the elevator*
Teacher:	*What were to be determined?*
Pupil:	*The apparent weight of the person*
Teacher:	*How did you obtain the required relations?*
Pupil:	*The elevator was moving up so we used,* $W = mg + ma$
Teacher:	*How did you solve the problem?*
Pupil:	*We substituted the given values, rearranged the equations and found horizontal range*
Teacher:	*Did you face any difficulty in any stage?*
Pupil:	*Only in the beginning*

Step 3. Analogical Problem Solving

Teacher: *Now you have to solve the following problem going through all the steps we practiced today.*

(Teacher writes the analogical question on the black board)

A monkey of mass 40kg climbs up a rope that can withstand a maximum tension of 600N. What will happen to the rope if the monkey climbs up with an acceleration of $6m/s^2$*?*

(Students workout the problem individually or in small groups and report to the teacher)

<u>Lesson 25: Uniform Circular Motion</u>

Name of teacher: Shareeja Ali M C
Class : 11
Topic : Laws of Motion
Time : 1 hour

Objectives: To enable students to

- Draw a schematic diagram representing a given problem situation
- Identify different physical quantities given in a story problem
- Select appropriate equations to solve a problem
- Apply law of conservation of momentum

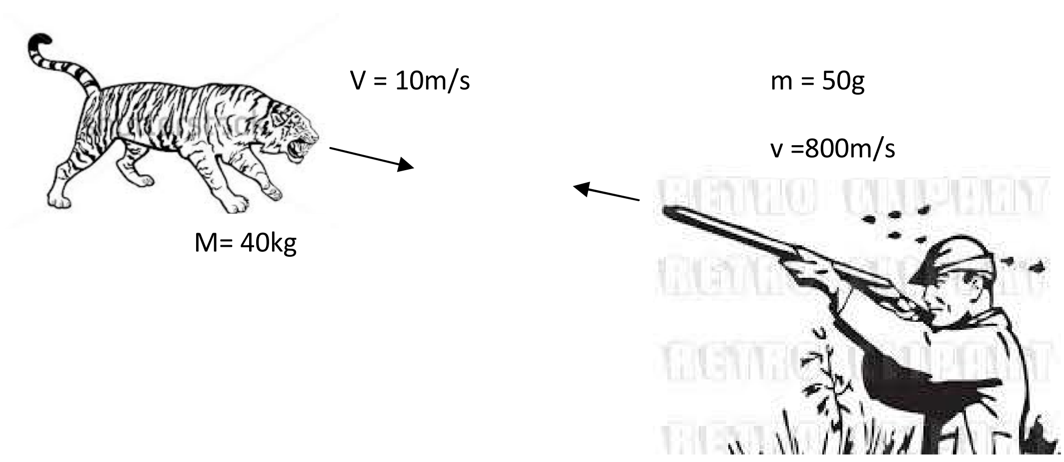
Resources: Concept map, diagrams

Phase 2: Presentation of the Problem

Teacher:	*A hunter has a machine gun that can fire 50g bullets with a velocity of 800m/s. A 40kg tiger springs at him with a velocity of 10m/s. How many bullets must the hunter fire into the tiger in order to stop it in its track? (Neglect pain).*

Phase 3: Problem solving procedure.

<u>Step 1: Surface representation</u>



Step 2: Structure Representation

Teacher:	*Let us discuss the motion of bullets and motion of tiger and how to balance their momentum. What is known about the tiger?*
Pupil:	*It has a mass of 40kg and speed of 10m/s*
Teacher:	*What is known about the bullets?*
Pupil:	*They have a mass of 50g and speed of 800m/s*
Teacher:	*What is to be determined?*
Pupil:	*Number of bullets that can stop the tiger*
Teacher:	*To stop a moving body, what is required?*
Pupil:	*Force*
Teacher:	*Which law helps to calculate force from mass and velocity?*
Pupil:	*Newton's second law, $F = dp/dt$*

Step 3: Planning the solution

Teacher:	*Let us now plan which equation can we use and how can we solve the problem.*
Pupil:	*Yes*
Teacher:	*When the bullet hits the tiger its momentum changes to zero. What is change in momentum of a single bullet?*
Pupil:	$m \times v$
Teacher:	*What is total change in momentum of 'n' bullets?*
Pupil:	$n \times m \times v$
Teacher:	*What is the momentum of the tiger?*
Pupil:	$M \times V$
Teacher:	*To stop the tiger, its momentum should be balanced by the momentum of the bullets. So which equation will we use here?*
Pupil:	$M \times V = n \times m \times v$
Teacher:	*Are all the quantities in SI?*
Pupil:	*No, mass of the bullet, m is in grams*
Teacher:	*Then convert it in to kg*
Pupil:	(Workout in their books)
	$50g = 50/1000\ kg$
	$=0.05\ kg$

Step 4: Implementing the plan

Teacher:	*Now we can proceed to calculate angular velocity*
	(Teacher work out on the black board)
	Substituting the values in equation,
	$MV = nmv$
	$40 \times 10 = n \times 0.05 \times 800$
	Therefore, $n = 40 \times 10 / 0.05 \times 800$
	$= 10$ *bullets*

Phase 4: Metacognitive Analysis

Step 1: Error Analysis

Teacher:	*The equation we used is,* $MV = nmv$
	Write the units used for each of the quantities and see whether they are the same for each term on either side of the equation.
Pupil:	(work out in their books)
	kg m/s =kg m/s
	The units for all the terms are the same.
Teacher:	*Therefore the equation is consistent unit wise.*

Step 2: Monitoring the Procedure

Teacher:	*What was your first step while solving the problem?*
Pupil:	*We drew a diagram showing a tiger jumping at a hunter. Then we labeled the mass and velocity of the tiger and the bullets*
Teacher:	*Which physical quantities were given directly?*
Pupil:	*Mass and velocity of the tiger and the bullet was given*
Teacher:	*Which physical quantities were to be determined?*
Pupil:	*Number of bullets needed to stop the tiger*
Teacher:	*How did you obtain the required relations?*
Pupil:	*We revised Newton's second law and observed that conservation of momentum can be applied to solve this problem*
Teacher:	*How did you solve the problem?*
Pupil:	*We substituted the given values, rearranged the equations and found number of bullets*
Teacher:	*Did you face any difficulty in any stage?*
Pupil:	*Only in the beginning stage*

Step 3. Analogical Problem Solving

Teacher: *Now you have to solve the following problem going through all the steps we practiced today.*

(Teacher writes the analogical question on the black board)

A stone weighing 50kg is rolling towards a person with a speed of 8m/s. If the person has a machine gun that can fire 50g bullets with a speed of 1000m/s, how many bullets can stop the stone?

(Students workout the problem individually or in small groups and report to the teacher)

Lesson 26: Inclined planes and coefficient of friction

Name of teacher	:	Shareeja Ali M C
Class	:	11
Topic	:	Laws of Motion
Time	:	1 hour

Objectives: To enable students to

- Draw a schematic diagram representing a given problem situation
- Identify different physical quantities given in a story problem
- Select appropriate equations to solve a problem
- Estimate inclination of a plane
- Estimate coefficient of friction between a body and a surface

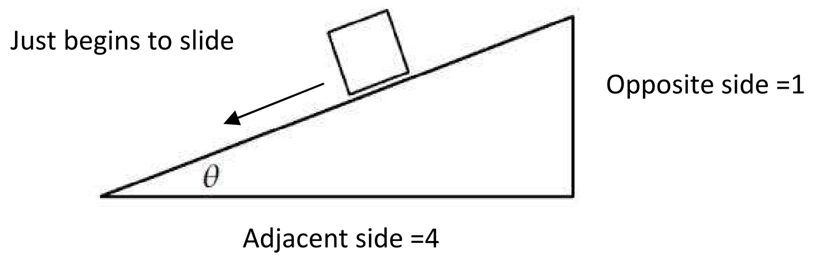
Resources: Concept map, diagrams

Phase 2: Presentation of the Problem

Teacher:	*A body placed on a rough inclined plane just begins to slide when slope of the plane is 1 in 4. Calculate coefficient of friction.*

Phase 3: Problem solving procedure.

Step 1: Surface representation



Step 2: Structure Representation

Teacher:	*Let us discuss inclined planes and their slops.*
	What is the slope of a plane?
Pupil:	*slope =* $\tan\theta$
Teacher:	*What is* $\tan\theta$*?*
Pupil:	*Opposite side / adjacent side*
Teacher:	*When you did the experiment with your note book and eraser in the previous class, you raised one side of the inclined plane till the note book just slided.*
Pupil:	*Yes.*
Teacher:	*Then what did you find out?*
Pupil:	*Angle of inclination*
Teacher:	*Then how did you find coefficient of friction?*
Pupil:	*Using the equation,* $\tan\theta = \eta$

Step 3: Planning the solution

Teacher:	*Let us now plan which equation can we use and how can we solve the problem.*
Pupil:	*Yes*
Teacher:	*In this problem which quantities are given?*
Pupil:	*Opposite side and adjacent side*
Teacher:	*What is to be determined?*
Pupil:	*Coefficient of friction*
Teacher:	*Which equation will you use?*
Pupil:	$\eta = \tan\theta$
	=opposite side/ adjacent side
Teacher:	*Do we have to make any unit conversions?*
Pupil:	*No*
Teacher:	*Why?*
Pupil:	$\tan\theta$ *and* η *do not have units*

Step 4: Implementing the plan

Teacher:	*Now we can proceed according to our plan.* (Teacher work out on the black board) *Substituting in equation,* $\eta = \tan\theta$ *=opposite side/adjacent side* *=1/4* *=0.25*

Phase 4: Metacognitive Analysis

Step 1: Error Analysis

Teacher:	*The equation we used is,* $\eta = \tan\theta$ *Do we have to check their unit wise consistency?*
Pupil:	No.

Step 2: Monitoring the Procedure

Teacher:	*What was your first step while solving the problem?*
Pupil:	*We drew the diagram of an inclined plane and marked opposite side and adjacent side.*
Teacher:	*What were the physical quantities given directly?*
Pupil:	*Opposite side and adjacent side*
Teacher:	*Which physical quantities were to be determined?*
Pupil:	*Coefficient of friction*
Teacher:	*Which equation did you use?*
Pupil:	*We used* $\eta = \tan\theta$
Teacher:	*Did you face any difficulty in any stage?*
Pupil:	*In the planning stage. But now it is clear.*

Step 3. Analogical Problem Solving

Teacher:	*Now you have to solve the following problem going through all the steps we practiced today.* (Teacher writes the analogical question on the black board) *A body placed on a rough inclined plane just begins to slide when the angle of inclination becomes 30^0. Calculate the coefficient of friction of the inclined plane.*

(Students workout the problem individually or in small groups and report to the teacher)

Lesson 27: Vertical and Horizontal components of Force

Name of teacher	: Shareeja Ali M C
Class	: 11
Topic	: Laws of motion
Time	: 1 hour

Objectives: To enable students to

- Draw a schematic diagram representing a given problem situation
- Identify different physical quantities given in a story problem
- Select appropriate equations to solve a problem
- To resolve a vector in to horizontal and vertical components
- To compute horizontal and vertical components of a vector

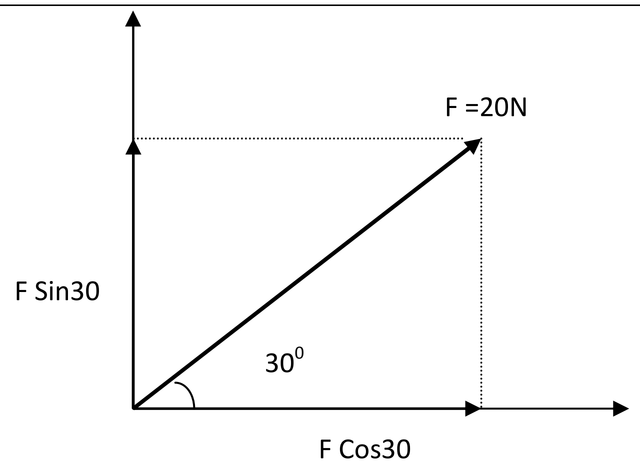
Resources : Concept map, diagrams

Phase 2: Presentation of the Problem

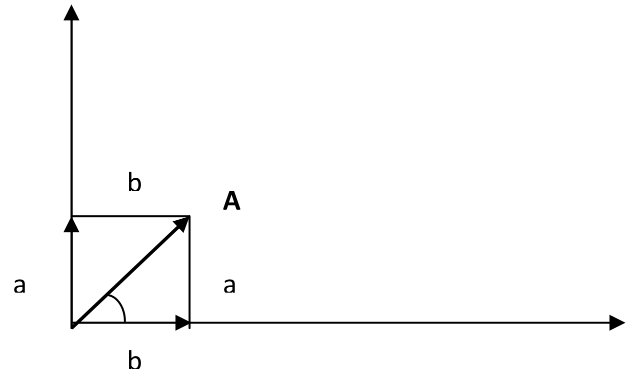
Teacher: *A force of 20N is applied on a hockey ball at an angle 30^0 with the X-axis. What is the vertical component of force?*

Phase 3: Problem solving procedure.

Step 1: Surface representation



Step 2: Structure Representation

Teacher:	*Let us discuss how to resolve a vector in to horizontal and vertical components.*
	What is the difference between a vector and a scalar?
Pupil:	*Vectors have direction*
Teacher:	*What are the two directions we discussed in the unit on two dimensions?*
Pupil:	*Horizontal and vertical directions*
Teacher:	*Let me express a vector in the form of a line with an arrow in the direction of the vector.*
	
	***A** is a vector having magnitude A and making angle θ with the horizontal direction.*
	What is Sinθ?
Pupil:	*Sin θ = a/A*
Teacher:	*Therefore, a = A Sinθ. This is called vertical component of vector **A.***
	What is Cosθ?
Pupil:	*Cos θ = b/A*
Teacher:	*Therefore, b= A Cos θ. This is called horizontal component of vector **A**.*

Step 3: Planning the solution

Teacher:	*Let us now plan what equations can be used and how we can solve the problem.*
Pupil:	*Yes*
Teacher:	*What are the quantities given in the problem?*
Pupil:	*Magnitude of force and the angle it makes with the horizontal*

Teacher:	*Force is a vector or a scalar?*
Pupil:	*Vector*
Teacher:	*Therefore we can resolve it in to horizontal and vertical components.* *What is to be determined?*
Pupil:	*Vertical component of force*
Teacher:	*How will you calculate vertical component of force?*
Pupil:	*Vertical component = F Sinθ*
Teacher:	*Is F given in SI unit?*
Pupil:	*Yes*
Teacher:	*So, do we have to make unit conversions?*
Pupil:	*No*

<u>Step 4: Implementing the plan</u>

Teacher:	*Now we can proceed according to our plan.* (Teacher work out on the black board) *Substituting the values in equation,* $F\ Sin\theta = 20\ Sin30$ $= 20\times0.5$ $=10N$

Phase 4: Metacognitive Analysis

<u>Step 1: Error Analysis</u>

Teacher:	*The equation we used is,* *Vertical component of Force = F Sinθ* *Write the units used for each of the quantities and see whether they are the same for each term on either side of the equation.*
Pupil:	(work out in their books) *Vertical component of Force = F Sinθ* $N = N$ *The units for all the terms are the same.*
Teacher:	*Therefore the equation is consistent unit wise.*

Step 2: Monitoring the Procedure

Teacher:	*What was your first step while solving the problem?*
Pupil:	*We drew a diagram showing the resolution of a vector in to horizontal and vertical components*
Teacher:	*Which physical quantities were given directly?*
Pupil:	*Magnitude of force and its angle with the horizontal*
Teacher:	*Which physical quantities were to be determined?*
Pupil:	*Vertical component of force*
Teacher:	*Which equations were used?*
Pupil:	*Vertical component of Force = F Sin*θ
Teacher:	*What assumptions did we make?*
Pupil:	*We didn't make any particular assumption*
Teacher:	*Did you face any difficulty in any stage?*
Pupil:	*No*

Step 3. Analogical Problem Solving

Teacher:	*Now you have to solve the following problem going through all the steps we practiced today.* (Teacher writes the analogical question on the black board) *A cricketer throws a ball with a force of 15N making an angle of* 40^0 *with the horizontal. What is the horizontal component of force?*

(Students workout the problem individually or in small groups and report to the teacher)

Lesson 28: Friction on Accelerated Bodies

Name of teacher: Shareeja Ali M C
Class : 11
Unit : Laws of Motion
Time : 1 hour

Objectives: To enable students to

- Draw a schematic diagram representing a given problem situation
- Identify different physical quantities given in a story problem
- Select appropriate equations to solve a problem
- Estimate the resultant force on a body
- Estimate frictional force on a body from coefficient of friction and mass of the body
- Estimate acceleration of a body taking friction in to account

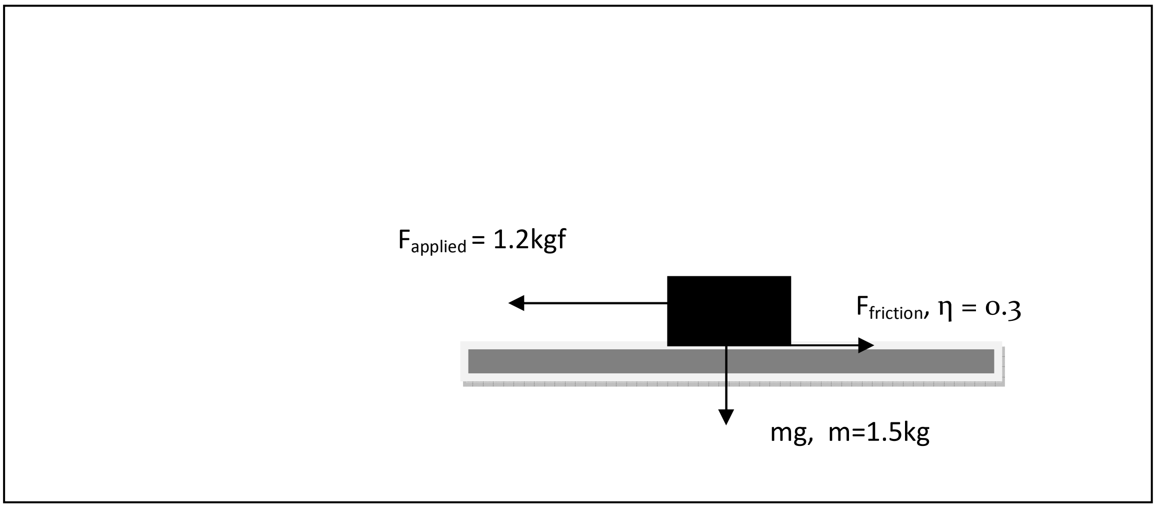
Resources: Concept map, diagrams

Phase 2: Presentation of the Problem

Teacher:	*A boy is playing with a ball in a train moving with a speed of 100km/h. If he throws the ball up with a speed of 10m/s. How long will the ball stay in air before reaching his hands?*

Phase 3: Problem solving procedure.

Step 1: Surface representation



Step 2: Structure Representation

Teacher:	*Let us discuss what forces act on the body and in which direction? What are the forces acting on the body?*
Pupil:	*Applied force and friction*
Teacher:	*Are they in the same direction?*
Pupil:	*No. They are in opposite direction.*
Teacher:	*Then, what will be the resultant force?*
Pupil:	$F_{applied} - F_{friction}$
Teacher:	*This resultant force causes acceleration of the body. What is the equation connecting force and acceleration of the body?*
Pupil:	$F = ma$
Teacher:	*Therefore, we can write,*
	$ma = F_{applied} - F_{friction}$

Step 3: Planning the solution

Teacher:	*Let us now plan which equation can we use and how can we solve the problem.*
Pupil:	*Yes*
Teacher:	*How much is the applied force?*
Pupil:	*1.2kgf*
Teacher:	*Is this force in SI unit?*
Pupil:	*No*
Teacher:	*We can convert kgf in to N by multiplying with 9.8* *Convert 1.2kgf in to N*
Pupil:	*(Workout in their note book)*
	$1.2kgf = 1.2 \times 9.8\ N$
	$= 11.76\ N$
Teacher:	*How much is the frictional force?*
Pupil:	*It is not given*
Teacher:	*What quantities are given?*
Pupil:	*Coefficient of friction and mass are given*
Teacher:	*How can we calculate frictional force from them?*
Pupil:	$F_{friction} = \eta mg$ (Looking at the concept map)
Teacher:	*Then calculate* $F_{friction}$
Pupil:	*(Workout in their note book)*
	$F\ friction = \eta mg$
	$= 0.3 \times 1.5 \times 9.8$
	$= 4.41\ N$

Teacher:	*What is to be determined?*
Pupil:	*Acceleration of the body*
Teacher:	*Which equation can we use to find acceleration?*
Pupil:	$ma = F_{applied} - F_{friction}$

<u>Step 4: Implementing the plan</u>

Teacher:	*Now we can proceed according to our plan.* (Teacher work out on the black board) *Substituting the values in equation,* $ma = F_{applied} - F_{friction}$ $1.5 \times a = 11.76 - 4.4$ *Therefore,* $a = 7.36/1.5$ $= 4.9 m/s^2$

Phase 4: Metacognitive Analysis

<u>Step 1: Error Analysis</u>

Teacher:	*The equation we used is,* $ma = F_{applied} - F_{friction}$ *Write the units used for each of the quantities and see whether they are the same for each term on either side of the equation.*
Pupil:	(work out in their books) $ma = F_{applied} - F_{friction}$ $kgm/s^2 = N + N$ *The units for all the terms are the same.*
Teacher:	*Therefore the equation is consistent unit wise.*

<u>Step 2: Monitoring the Procedure</u>

Teacher:	*What was your first step while solving the problem?*
Pupil:	*We drew a diagram showing the direction and magnitude of different forces acting on the body*
Teacher:	*Which physical quantities were given directly?*
Pupil:	*Applied force, coefficient of friction and mass*
Teacher:	*Which physical quantities were to be determined?*
Pupil:	*Acceleration of the body*
Teacher:	*Which physical quantities did you calculate?*
Pupil:	*We calculated frictional force from coefficient of friction and mass*

Teacher:	*What assumption did you make?*
Pupil:	*We assumed that acceleration is caused by the resultant force on the body*
Teacher:	*Where all the quantities in SI unit?*
Pupil:	*No. We converted kgf in to N by multiplying with 9.8*
Teacher:	*How did you solve the problem?*
Pupil:	*We substituted the given values, rearranged the equations and found acceleration of the block.*
Teacher:	*Did you face any difficulty in any stage?*
Pupil:	*During the planning stage*

Step 3. Analogical Problem Solving

Teacher:	*Now you have to solve the following problem going through all the steps we practiced today.*
	(Teacher writes the analogical question on the black board)
	A 2kg wooden block is resting on a surface of co-efficient of friction 0.35. How much acceleration will the wooden block have if a force of 2.8kgf is applied on it?

(Students workout the problem individually or in small groups and report to the teacher)

Lesson 29: Application of Newton's Second Law

Name of teacher	: Shareeja Ali M C
Class	: 11
Unit	: Laws of Motion
Time	: 1 hour

Objectives: To enable students to

- Draw a schematic diagram representing a given problem situation
- Identify different physical quantities given in a story problem
- Estimate acceleration of a body using Newton's second law
- Estimate the velocity of a body using equations of motion

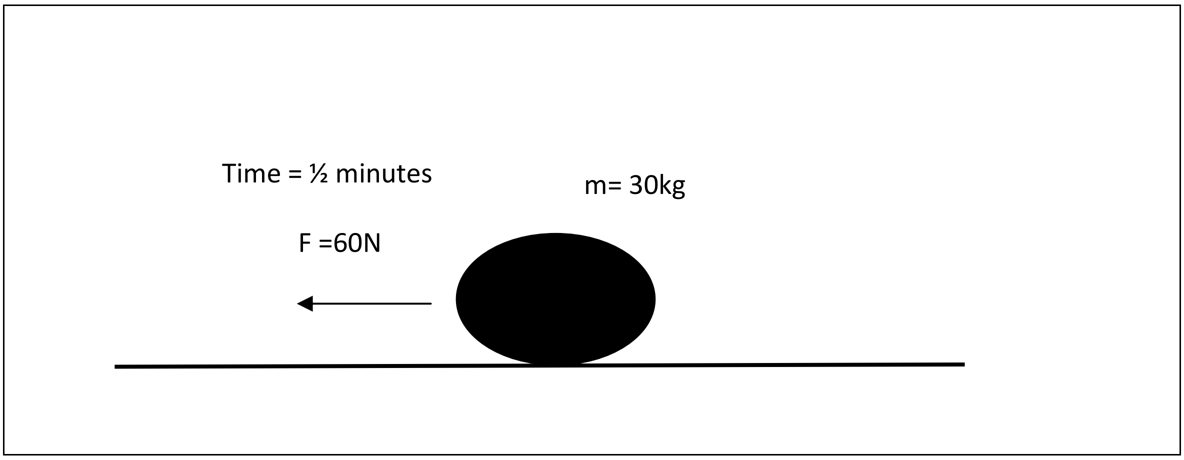
Resources : Concept map, diagrams

Phase 2: Presentation of the Problem

Teacher:	*A force of 60N is applied on a stone (which was initially at rest) of mass 3kg for ½ minute. Find the velocity gained by the stone.*

Phase 3: Problem solving procedure.

Step 1: Surface representation



Step 2: Structure Representation

Teacher:	*Let us discuss the motion of the stone on application of force. What is the force acting on the stone?*
Pupil:	*60N*
Teacher:	*What is the mass of the stone?*
Pupil:	*30kg*
Teacher:	*what will happen when we apply force on the stone?*
Pupil:	*It moves*
Teacher:	*Will it be accelerated?*
Pupil:	*Yes*
Teacher:	*Which law can we use to find acceleration?*
Pupil:	*Newton's second law, F =ma*
Teacher:	*What else is given in the question?*
Pupil:	*Time for which the force is applied*
Teacher:	*How much is the time?*
Pupil:	*½ minutes*
Teacher:	*Is time in SI units?*
Pupil:	*No. We can convert it.* *½ minutes = 30 seconds*
Teacher:	*Are the rest of the quantities in SI units?*
Pupil:	*Yes*

Step 3: Planning the solution

Teacher:	*Let us now plan how we can solve the problem.*
Pupil:	*Yes*
Teacher:	*What is to be determined?*
Pupil:	*Velocity*
Teacher:	*Is it final velocity or initial velocity to be determined?*
Pupil:	*Final velocity*
Teacher:	*How much is initial velocity?*
Pupil:	*Zero*
Teacher:	*Which equations of motion can we use to find final velocity?*
Pupil:	$v = u + at$
Teacher:	*We know u and t. Do we know a?*
Pupil:	*No, but we can calculate it from F = ma*
Teacher:	*Are all the given quantities in SI?*
Pupil:	*Time was in minutes, we converted it into seconds. The rest of the quantities are in SI.*

Step 4: Implementing the plan

Teacher:	*Now we can proceed according to our plan.* (Teacher work out on the black board) *To find acceleration, substituting the values in equation,* $F = ma$ $60 = 30 \times a$ *Therefore,* $a = 60/30$ $= 2 m/s^2$ *To find the velocity attained by the stone, substituting values in equation,* $v = u + at$ $= 0 + 2 \times 30$ $= 60 m/s$

Phase 4: Metacognitive Analysis

Step 1: Error Analysis

Teacher:	*We used the equation* $F = ma$ *And* $v = u + at$ *Write the units used for each of the quantities and see whether they are the same for each term on either side of the equation.*
Pupil:	(work out in their books) $F = ma$ $N = kg\ m/s^2$ *The units for all the terms are the same.* $v = u + at$ $m/s = m/s + m/s^2 \times s$ $m/s = m/s + m/s$
Teacher:	*Therefore the equations are consistent unit wise.*

Step 2: Monitoring the Procedure

Teacher:	*What was your first step while solving the problem?*
Pupil:	*We drew a diagram showing the force acting on a stone and its mass and the time for which the force was acting.*
Teacher:	*Which physical quantities were given directly?*
Pupil:	*Force acting on the stone, time for which the force was acting and the mass of the stone*
Teacher:	*Which physical quantities were to be determined?*
Pupil:	*The final velocity of the stone*
Teacher:	*Which equations were used?*
Pupil:	*$F = ma$, to find acceleration, and* *$v = u + at$, to find velocity attained by the stone*
Teacher:	*Did you make any unit conversions*
Pupil:	*Yes, we converted time in minutes to seconds*
Teacher:	*What assumptions did you make?*
Pupil:	*We assumed that the acceleration is uniform, otherwise equation of motion cannot be used.*
Teacher:	*Did you face any difficulty in any stage?*
Pupil:	*No*

Step 3. Analogical Problem Solving

Teacher:	*Now you have to solve the following problem going through all the steps we practiced today.* (Teacher writes the analogical question on the black board)
	A stone of mass 2kg is initially at rest. What force if applied for 20 seconds will make it move with a speed of 600m/s?

(Students workout the problem individually or in small groups and report to the teacher)

Lesson 30: Two Body Motion on a Pulley

Name of teacher	:	Shareeja Ali M C
Class	:	11
Topic	:	Laws of Motion
Time	:	1 hour

Objectives: To enable students to

- Draw a schematic diagram representing a given problem situation
- Identify different physical quantities given in a problem
- Mark the direction of forces on a string
- Balance forces on different masses on a string passing through a pulley
- Simultaneously solve two equations

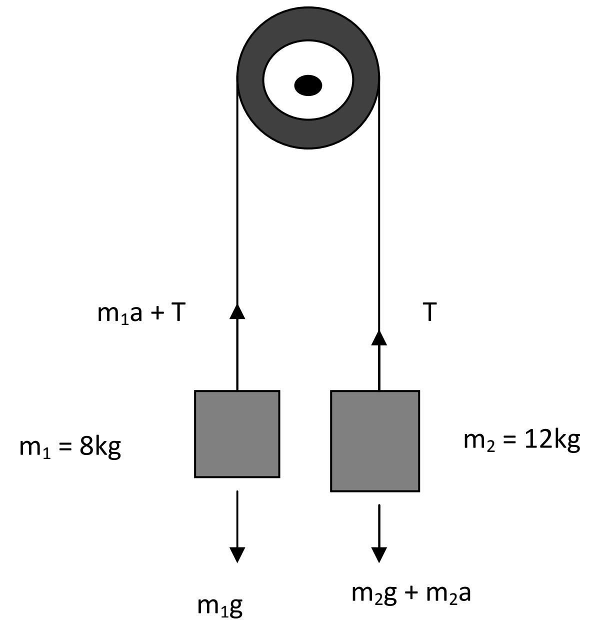
Resources: Concept map, diagrams

Phase 2: Presentation of the Problem

Teacher: *Two masses 8kg and 12kg are connected at the two ends of a light inextensible string that goes over a frictionless pulley. Find the acceleration of the masses, and the tension in the string when the masses are released.*

Phase 3: Problem solving procedure.

Step 1: Surface representation



Step 2: Structure Representation

Teacher:	*Let us discuss the motion of the two masses on a pulley.* *What are the given masses?*
Pupil:	*8kg and 12kg*
Teacher:	*Let us name 8kg as* m_1 *and 12kg as* m_2. *Which of these masses will move down?*
Pupil:	*12kg or* m_2
Teacher:	*What are the forces acting at the* m_2 *end?*
Pupil:	m_2g *downwards and tension on the string upwards*
Teacher:	*Since the mass is moving downwards with an acceleration a, there will be a force* m_2a *acting downwards?* *So what will be the total downward force?*
Pupil:	$m_2g + m_2a$
Teacher:	*What will be the total upward force?*
Pupil:	*T, tension*
Teacher:	*By Newton's third law we can take total upward force as equal to total upward force as equal to total downward force.* *Therefore,* $T = m_2g + m_2a$ *Now, let us consider the* m_1 *end. What are the forces acting at the* m_1 *end?*
Pupil:	m_1g *downwards and tension on the string upwards*
Teacher:	*Since* m_1 *is also moving with the same acceleration, there will be an additional force* m_1a. *In which direction will it act?*
Pupil:	*Upwards, because* m_1 *is moving upwards*
Teacher:	*Now, can you use Newton's third law and write the balanced force equation at the* m_1 *end.*
Pupil:	$T + m_1a = m_1g$

Step 3: Planning the solution

Teacher:	*Let us plan which equations to use and how to solve this problem.* *What are the quantities given?*
Pupil:	*The two masses* m_1 *and* m_2
Teacher:	*What is to be determined?*
Pupil:	*Tension on the string, T and acceleration, a.*
Teacher:	*What are the equations connecting masses, tension and acceleration?*
Pupil:	$T = m_2g + m_2a$

	$T + m_1a = m_1g$
Teacher:	*We have to solve these equations simultaneously to solve tension on the string and acceleration.*
	Are the masses given in SI units?
Pupil:	*Yes, they are in kg*

Step 4: Implementing the plan

Teacher:	*Now we can proceed according to our plan to solve the problem.* (Teacher work out on the black board) *Substituting the masses in the equations,* $T = m_2g + m_2a$ $T + m_1a = m_1g$ *We get,* $T = 12\times9.8 + 12a$ --------(1) $T + 8a = 8\times9.8$ -------(2) *Or* $T= 120 + 12a$ -------(3) $T= 80 - 8a$ -------(4) *To solve these two equations we can make the factors of a same by dividing equation (3) by 6, and equation (4) by 4. Thus we get,* $T/6 = 20 + 2a$ ------(5) $T/4 = 20 - 2a$ ------(6) *Now we can make a single equation with one unknown quantity, T by adding the two equations (6) and (5)* $T/6 + T/4 = 40$ ------(7) *Now, multiplying equation (7) with 24 which is the least common multiple of 4 and 6, we get* $4T + 6T = 960$ $10T = 960$ *Therefore,* $T = 96$ *N* *To find acceleration let us substitute the value of tension in equation (3)* $96 = 120 + 12a$ $12a = 96 - 120$ $12a = 24$ *Therefore,* $a = 24/12$ $= 2\ m/s^2$

Phase 4: Metacognitive Analysis

Step 1: Error Analysis

Teacher:	*The equations we used were,* $T = m_2g + m_2a$ $T + m_1a = m_1g$ *Write the units used for each of the quantities and see whether they are the same for each term on either side of the equation.*
Pupil:	(work out in their books) $T = m_2g + m_2a$ $N = kgm/s^2 + kgm/s^2$ *The units for all the terms are the same.* $T + m_1a = m_1g$ $N = kgm/s^2 + kgm/s^2$ *The units for all the terms are the same.*
Teacher:	*Therefore the equation is consistent unit wise.*

Step 2: Monitoring the Procedure

Teacher:	*What was your first step while solving the problem?*
Pupil:	*We drew a diagram showing two masses hanging on a pulley*
Teacher:	*What were the physical quantities given?*
Pupil:	*Masses were given.*
Teacher:	*Which physical quantities were to be determined?*
Pupil:	*Tension on the string and acceleration of the masses*
Teacher:	*Which equation did you use?*
Pupil:	*We used two equations,* $T = m_2g + m_2a$ $T + m_1a = m_1g$
Teacher:	*How did you get these equations?*
Pupil:	*We determined the forces acting on each of the masses and the string and applied Newton's third law.*
Teacher:	*were all the quantities given in SI?*
Pupil:	*Yes*
Teacher:	*How did you solve the problem?*
Pupil:	*We substituted the given values in the equations and simultaneously solved two equations for finding out tension on the string and acceleration of the masses*
Teacher:	*Did you face any difficulty in any stage?*
Pupil:	*Yes, both in the planning and implementing stage. But now the strategy is clear.*

<u>Step 3. Analogical Problem Solving</u>

Teacher:	*Now you have to solve the following problem going through all the steps we practiced today.* (Teacher writes the analogical question on the black board)
	A string can withstand a maximum tension of 100N. Two masses 10kg and 8kg are connected at its ends and the string goes over a frictionless pulley. Will the string break when the masses are released?

(Students workout the problem individually or in small groups and report to the teacher)