Effect of a Metacognitive Strategy Instruction on Problem Solving in Newtonian Mechanics among Vocational Higher Secondary Students

Abdul Gafoor K.,*
Shareeja Ali M.C.**

Abstract
In view of intellectual and pedagogic challenges for students and teachers in understanding and teaching problem solving, this study reports findings on development of a strategy that encourage physics teachers to focus on a metacognitive approach to solving well-structured problems in Newtonian mechanics. It employs a pre-test post-test control group quasi-experimental design on two intact groups of 21 students each of Class 11 from vocational higher secondary school, matched one to one based on pre-test. Although Metacognitive Strategy Instruction is found significantly contributing to problem solving, the study recommends consideration of the strategy on other areas of physics and allied sciences.

Introduction

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 educational endeavours. Sciences are centrally concerned with developing and systematizing knowledge that is useful for solving various kinds of problems. Hence, education in the sciences must address the crucially important task of teaching students to become proficient problem solvers. Problem solving is a very sophisticated cognitive skill. Hence, understanding and teaching problem solving is of paramount importance. Nevertheless, it is perceived intellectually as well as pedagogically challenging for students and teachers.

Problem solving in Education

Initial researches related to problem solving focused on artificial puzzles and general problem-solving strategies (Newell & Simon, 1972; Reed, Ernsyt & Banerji, 1974). Problem-solving research then switched to knowledge-based representations, such as schemata and to domain specific strategies (Anderson, Greeno, Kline and Neves, 1981; Mayer, 1983; Heller & Rief, 1984).

Most of the initial domain specific problem-solving researches concentrated on comparing strategies adopted by experts and novices (Simon & Simon, 1978). However, these studies could not develop a general instructional guideline for problem-solving, because the tasks were only genuine problems for the novices, not for the experts.

Later, studies attempted to find out the strategies adopted by students and the different factors influencing them. (Mayer, 1992; Robertson, 1990; Gaigher , Rogan & Braun 2006; Gerace & Beatty, 2005). These studies revealed that out of the various strategies like problem-solving heuristics, modelling methods, means-ends analysis, search-based strategies and schema based strategies, those strategies that incorporate metacognition facilitate reflective thinking. Recent studies examine how metacognition helps problem-solving (Anderson & Nashon, 2006).

Enhancing Problem-solving Through Instruction

There are varied perspectives and approaches to instruction of science, with uneven degree of emphasise on problem-solving in science. Constructivism and situated cognition argue for the domain specificity of any performance and therefore recommend embedding instruction in some authentic context (Jonassen & Land, 2000). Adopting this perspective, the context selected for instruction in present study is solving well-structured story problems in physics, especially Newtonian mechanics.

Present study attempts to incorporate the factors viz., integrated knowledge structure and use of metacognitive strategy by exploring the possibility of developing a classroom strategy that would encourage physics teachers to put greater focus on a metacognitive approach to problem solving.

Does Metacognitive Strategy Instruction Influence Problem solving?

Conceptual knowledge and problem scheme knowledge are good predictors of, and have independent effects on, problem solving ability (Friege & Lind, 2006). Structuring knowledge by means of external representation of problem situations through symbols and objects can facilitate complex cognitive processing during problem solving. Hence, explicit teaching in organizing the knowledge can enhance students' performance on problem solving. For this, present study employs concept maps on selected topics to organise the conceptual knowledge to help students internalise the required concepts, facilitating their retention for problem solving.

Recent studies on enhancing domain specific problem solving strongly recommend the use of metacognitive strategies as students may not know how to use the instruction effectively (Roll, Aleven, McLaren, Ryu, Baker & Koedinger, 2006). If metacognition is taught to students their problem solving skills will be improved. This is because high metacognitive skills can compensate for deficit in overall ability by providing knowledge about their own cognition.

Present study investigates the impact of a set of procedures specifically developed and explicitly taught to students to help in elaborating their own strategies while solving the problems and to encourage reflective thinking. This procedure echoes a list of metacognitive skills related to problem solving by Larkin (2006) that include orientation, planning, evaluation and elaboration. Metacognitive skills or reflective practice can be described as the "sign of maturity" in problem solving.

The scope of the present study is limited to the test the impact of Metacognitive Strategy Instruction (MSI) on problem solving skills in Newtonian mechanics, by employing a pre-test post-test control group quasi-experimental design. Newtonian mechanics is selected as the domain because it is fundamental to physics and can easily be linked with everyday life activities. Conducted on a sample of vocational higher secondary school that has relatively low-achievers for whom mechanics supposedly very difficult and who do not usually attempt to solve problems in physics, the strategy and results from this study may prove useful to a wider population of teachers and students.

Methodology

Objectives of the Study

1. To tryout MSI for enhancing problem solving ability in Newtonian mechanics of vocational higher secondary students
2. To test the effect of MSI on problem solving ability in Newtonian mechanics of vocational higher secondary students

Sample

Sample comprises two intact groups of 21 students each of Class 11 from vocational higher secondary school. Members in the groups were matched one to one based on the pre-test. These students are relatively low achievers in physics who passed Secondary School Leaving Examination with scores ranging between 35 to 50 percent. One month before the pre-test for this study, students of both experimental and control groups had received regular instruction on 'Newton's Laws of Motion' for a period of seven hours. Regular instruction in physics in higher secondary classes comprise of lecture classes followed by students individually working on teacher guided practise problems. Hence, these groups have already attempted to work out, with teacher assistance, at least eight problems on Newtonian physics.

Metacognitive Strategy Instruction

Metacognitive Strategy Instruction consists of the following four phases.

I. Presentation of the knowledge domain as concept maps

II. Presenting well-structured academic story problems

III. Problem solving Procedure under the guidance of the teacher with the following steps

   1. Surface Representation that requires semantic comprehension of relevant textual information and generation of an initial problem description
   2. Structure Representation where students generate a theoretical description of the problem by identifying the relevant principles and relations
   3. Planning the Solution by identifying values of physical quantities provided in the story and designing an appropriate algorithm to solve the problem
   4. Implementing the Plan to generate the solution

IV. Metacognitive Analysis facilitating reflective thinking among the learners

Measure

Two parallel tests of problem solving in Newtonian mechanics, each consisting of six well-structured story problems from classical mechanics were used as pre and post-tests. Each test carries a maximum score of 30, i.e., 5 scores per item. Pre test helped to match the two groups on previous problem solving skills in the topic selected for study.

Results

Comparison of post-test scores of the experimental and control group

The post-test scores of problem solving of the experimental and control groups were compared using the method of significance of the difference between means in small independent samples (Garrett 2004).

Mean score of the experimental group: 12.4

Mean score of the control group: 2.9

SD: 4.54

SE_D: 1.40

t value: 6.79

The 't' score obtained for the comparison of post test scores of experimental and control group is 6.79 ($p < .01$; 40 df) and hence the difference between the mean score is significant. Therefore, MSI is effective in enhancing problem solving skills in Newtonian mechanics among vocational higher secondary students. Figure 1 visually demonstrates the effect of MSI on problem solving in Newtonian mechanics.

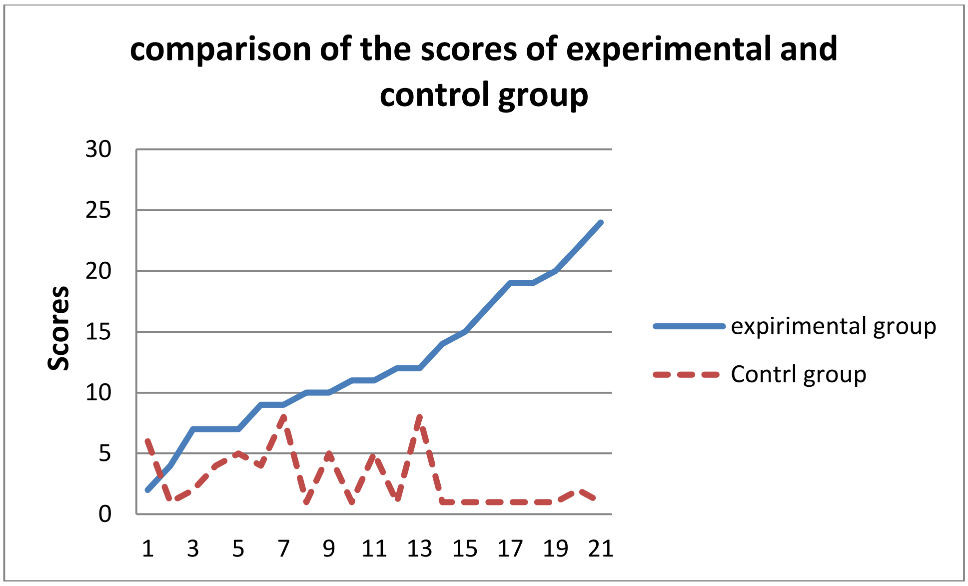

Figure 1: Effect of MSI on the experimental group

An inspection of the scores obtained for the experimental and control group reveals that though both of the groups were matched based on their previous problem solving ability, in the post test 76% of the experimental group students could get a pass mark (30% for Higher secondary school students) while none from the control group passed.

Comparison of pre and post-test scores of the experimental group

The pre-test and post-test scores of problem solving were compared using "difference method" for a single small group (Garrett 2004).

Mean of pre-test scores: 4.05
Mean of post-test scores: 12.4
SD_D: 5.38
SE_{MD}: 1.175
t value: 7.12

The 't' score obtained for the comparison of pre and post test scores is 7.21 ($p< .01$; 20 df) and hence gain from pre-test to post-test is significant. Thus, MSI significantly contributes to the improvement of problem solving in Newtonian mechanics among vocational higher secondary students. Figure 2 visually demonstrates the impact of MSI on problem solving in Newtonian mechanics.

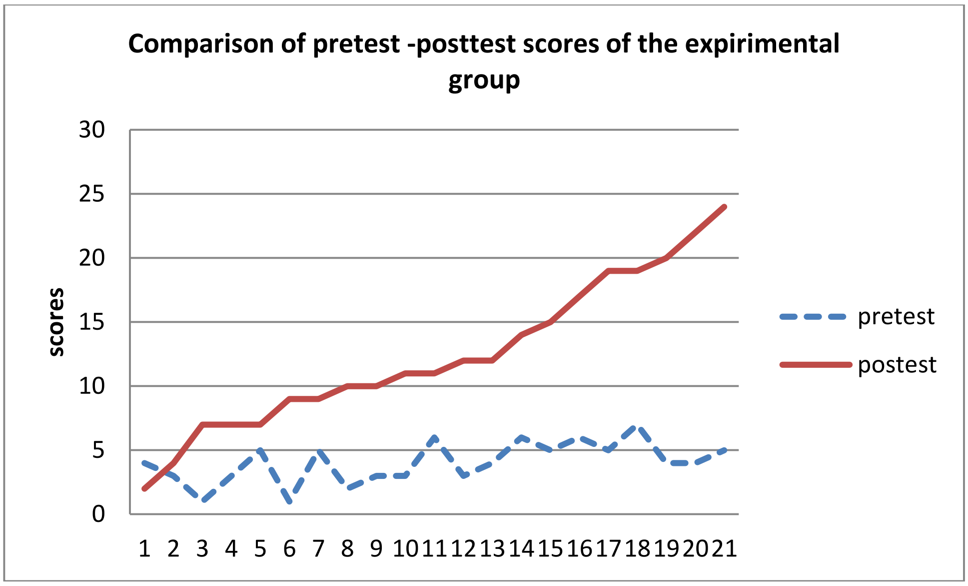

Figure 2: Gain in Problem Solving After Metacognitive Strategy Instruction

The pre-test scores obtained by the group ranged between 1 and 7 (out of 30) which reveals that students performance even after regular instruction on Newton's law of motion is very poor and none of the students in the group could get a pass mark (30% for Higher secondary school students). After the MSI for three hours within a week, the posttest scores of this group ranged from 2 to 24. Only five students scored below 9, the required score for a pass, i.e., after MSI 76 percentage of students could acquire a pass score on the test. Moreover one third of students could achieve 50 percent or above on the post-test. Further, all the students improved on the problem solving performance after the treatment.

Conclusion

The effect of MSI on problem solving in Newtonian mechanics is evidenced by the present study. The usefulness of such strategies on other areas of physics and allied sciences need consideration. Though investigators could get a glimpse of what it really means to structure the problem and aid reflective thinking among students, the strategy requires further refinement, especially, by incorporating an analogical problem to monitor the problem solving procedure as the final part of each metacognitive instruction practice.

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