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Effect of Higher Order Thinking Instructional Model on Scientific Reasoning of Grade VIII Students

Khateeb Ahmed Khan* and Rizwan Akram Rana**

Abstract

This study focused on finding out the influence of higher order thinking instructional model on grade VIII students' scientific reasoning. The quasi-experimental nonequivalent control group design was used to conduct this study. Experiment was conducted on 62 grade VIII students from a public higher secondary school of district Lahore, Pakistan. These students were taken as intact groups and were divided into experimental group and control group randomly. Experimental group comprised 30 students while control group comprised 32 students. Both groups were pretested for their scores of scientific reasoning using Lawson's Classroom Test for Scientific Reasoning (LCTSR). Lesson plans based on higher order thinking instructional model were developed and an intervention of 24 weeks was given to the students. Students were taught using the developed lesson plans based on higher order thinking instructional model. A posttest of scientific reasoning was taken at the end of intervention. Data were analyzed using the independent samples t-test to find the effect of higher order thinking instructional model on scientific reasoning. Results suggest that the students in both experimental and control groups were at the same level of scientific reasoning before the start of intervention. However, students in experimental group, taught by using higher order thinking instructional model, performed better in posttest than those in control group. Overall results revealed that higher order thinking instructional model influenced the scientific reasoning of grade VIII students. It was recommended that there is a need to adopt this higher order thinking instructional model for not only to make students think in higher order domain but to reason scientifically as well.

Keywords: Higher order thinking, instructional model, scientific reasoning, science learning, and reflective thinking.

*PhD Scholar, Institute of Education and Research, University of the Punjab, Lahore, Pakistan, Email: khateeb.pu@gmail.com
** Head, Department of Education. University of Lahore, Email: drrarpu@gmail.com

Introduction

Our everyday life is becoming more dependent on science and technology day by day. Science is not only making the life of humans easy but also providing solutions to the problems being faced in daily life (Goodrum, Druhan, & Abbs, 2012). There will be a pivotal role of science education in developing scientific literacy for the younger generation of Pakistan. It will ultimately build a stronger future of the nation. Science education is vital as it ensures that citizens have the confidence, knowledge, and skills to participate actively in an increasingly complex scientific and technological world (Kambeyo & Csapo, 2018). Science education aims at providing a solid base of science for students. This will enable them to create opportunities for science-related occupations and activities appropriate to their interests and abilities (Ministry of Education, 2006). Teachers need to develop these interests and abilities at the early stage of learning science. Students who choose to study science as a major at secondary level, are not only needed but also expecting the coursework and laboratory work which will ultimately evolve them into a scientist. Students' selection of science as a subject and making it a career, heavily depends upon the way they were taught science, their level of enjoyment, interest, and perceptions (Palmer, Burke, & Aubusson, 2017).

Many teaching and learning strategies are suggested to keep students' interest in science and make lifelong learning for them. Ministry of Education (2006) also reveals that constructivist theory of learning to be implemented to attain the goals mentioned in National Education Policy. A learning theory based on Piaget's (1957) work on child psychology is known as constructivism. It is a theory of learning where a child passes through different stages constructing the knowledge. Several models related to constructivist approaches were introduced. Biological Science Curriculum Study (BSCS) introduced one of such constructivist-based models comprised five-phases and usually it is called 5Es instructional model. Each E in 5Es represents: Engagement, Exploration, Explanation, Elaboration, and evaluation (Bybee & Landes, 1990; Trowbridge, Bybee, & Carlson-Powell, 2004; Abell & Volkman, 2006). However, it was noted by Bybee et al. (2006) that this 5Es instructional model is not extensive and it could be more refined. This 5Esinstructional model was then used to construct an extensive model which included Science Process Skills (SPS) and Reflective Thinking (RT) to develop Higher Order Thinking (HOT) skills in students.

5Es instructional model is the base of Higher Order Thinking (HOT) and included the Science Process Skills (SPS) and Reflective Thinking (RT) in its developmental phases. The first phase of HOT instructional model is engagement as it is in the 5E model. The exploration, second phase, is replaced with investigation. The experts in the field of education recommended improving children's knowledge to a superior degree using sub-phases: noting down the processes of investigation, planning the investigation, regulating variables, and devising hypotheses (Singer & Moscovici, 2008). The third phase in HOT instructional model is explanation. At this stage, a particular characteristic of the children's engagement and investigation is highlighted so that children are offered the chance to express their knowledge and explicate the ideas in their own words. This explanation stage is analogous to Bybee et al.'s (2006) model where one specific feature of engagement and exploration is focused so that children can show their conceptual knowledge and skills. Conclusion is the fourth stage in the HOT instructional model. The aim of this phase is to extend students' theoretical knowledge and let them to simplify recently discovered ideas, and to create conclusions through these new experiences. Reflection is the final phase of HOT instructional model. Feedback on the procedures in prior phases is made by taking time to evaluate the problem faced at the start of process, the action taken to resolve that problem, and examine the inferences in this phase.

This study focused on using HOT instructional model to develop scientific reasoning in students. Scientific reasoning has deep roots in the philosophy of science education which is ultimately related to progressive school of thought in education. Current research suggests that skills related to scientific reasoning trainable as well as transferable (Han, 2013). Zimmerman (2007) and Bao et al. (2009) mentioned that the capacity to thoroughly investigate a problem is known as scientific reasoning, develop and test the hypotheses, regulate and control variables, and evaluate experimental results. Scientific Reasoning is explained in some other learning theories as well.

Intellectual development of human beings into developmental stages was introduced by in helder and Piaget (1958). The last two of the Piaget's developmental stages i.e., concrete operational and formal operational stages, are identical to Scientific Reasoning as advanced reasoning skills of an individual starts to develop these stages.

Concrete experiences become a base for concrete operational individuals and those concrete operational individuals having only the concrete experiences are not able to generate or create hypotheses because of such experiences. Hypotheses which are developed and generated by those individuals who have reached formal operational thinking, i.e., they use hypothetico-deductive reasoning. Each person may not attain such reasoning level as well as this reasoning level is not attained in each subject (Piaget, 1972), however these experiences still find fundamental place in the sciences.

Scientific reasoning has many similarities found by those who research informal reasoning. The procedure involved in argumentation, particularly the structure outlined by Toulmin (1958), reflects the process of inductive reasoning in science. In inductive reasoning several parts of data are provided to help a claim or hypothesis and these parts of data are supported by merits/explanations.

Observations construct knowledge rigorously and this knowledge contacts with the physical world is the main argument of individual constructivism and scientific inquiry. Current information or theory is used to analyze and understand this knowledge or evidence which ultimately is changed by the modern knowledge (von Glasersfeld, 1993). Modern knowledge is generated by scientific inquiry in the same way. Current base of knowledge is sharpened by the information from current knowledge through reflection on the results and shapes a conduct of inquiry (Hodson, 1996; Kuhn, 1996; Leonard, 1989). Generation of scientific knowledge through reasoning is related to all these learning theories, bearing on current theory. Considerable information regarding the promotion of scientific reasoning (deductive and inductive) has been collected using this epistemological evidence providing theoretical support to scientific reasoning in the classroom.

Researchers have found positive impact of scientific reasoning on educational success (Adey & Shayer, 1994) as well as a better relationship between students' abilities to scientifically reason and ways to increase knowledge in content related to science (Coletta & Phillips, 2005; Lawson et al., 2000). Adey and Shayer (1993) conducted a three-year long study and taught students with scientific reasoning skills. The students outperformed those who were not taught with scientific reasoning lesson plans.

Objectives

Following were the objectives of the study:

1. To describe the level of scientific reasoning of grade VIII students.
2. To investigate the impact of Higher Order Thinking instructional model on scientific reasoning of grade VIII students.

Research Question

Following research question was drawn to achieve the objective 1:

Q 1: What is the level of scientific reasoning of grade VIII students?

Research Hypotheses

Following null hypotheses were tested based on the objective 2:

$H_{01:}$ There is no significant mean difference between the control group's pretest and posttest scientific reasoning scores of grade VIII students.

$H_{02:}$ There is no significant mean difference between the experimental group's pretest and posttest scientific reasoning scores of grade VIII students.

H_{03}: There is no significant effect of HOT instructional model on scientific reasoning scores of grade VIII students.

Research Methodology

It was a nonequivalent pretest posttest control group design in quasi-experimental research. Two intact groups of Grade VIII were taken because randomization was not allowed by the administration at this grade considering it a high-stake examination. These groups were named as experimental group and control group and were assigned randomly.

Two already intact groups of Grade VIII from a public higher secondary school were chosen randomly. Control group consisted of 32 students while experimental group consisted of 30 students. Hence sample of the study was 62 students studying at grade VIII in a higher secondary school of Lahore, Pakistan.

Experimental Group	O	X_1	O
Control Group	O	X_2	O

Instrumentation

Data were collected by using Lawson's Classroom Test for Scientific Reasoning. Multiple-choice version of the Lawson's Classroom Test of Scientific Reasoning (LCTSR) developed by Lawson (2000) was used to measure the skills related to scientific reasoning of students in both pre-test and the post-test. The instrument has well established reliability and validity. Like, Lawson, Banks, and Logvin (2007) found reliability coefficient of 0.79 using internal-consistency in Kuder-Richardson 20. Conservation of weight and volume is the first aspect related to the reasoning ability used to measure by the LCTSR, second is probability, while proportionality is third, correlations, control of variables, and deductive reasoning are fourth, fifth and sixth ones. There are 12 scenarios in LCTSR. Each scenario consists of two questions. In each scenario, first part is related to the aspect of scientific reasoning while the second aspect asks why the first part is correct. It means, there is a reason to be provided in second part to each aspect asked in first part of scenario. Schen (2007) used LCTSR in introductory biology class and found positive results. Similarly, Coletta and Phillips (2005 & 2007) also found positive relationship ($r \approx 0.5$) between the students' reasoning abilities measured with Lawson's test and scores of pretest-posttest gain on the Force Concept Inventory. The instrument was pilot tested for its applicability in Pakistani context.

Pilot Testing

The instrument was translated into Urdu and pilot tested on 104 students of grade VIII. Instrument's construct validity was ensured using the factor analysis.

Lawson's Classroom Test of Scientific Reasoning is a two-tier test which means the respondents either have to mark each statement as right (1) or wrong (0). This test is further divided into 12 parts each part containing two questions. In each part first question contains information and second question is about the reason of being that information correct. Analysis were made because students might have marked the statement correct without being knowing the reason (1, 0 pattern) or students might know the reason, but their answer is incorrect (0, 1 pattern).

Table 1

Scores from groups of questions of LCTSR

Response Type	**Qs 1-2**	**Qs 3-4**	**Qs 5-6**	**Qs 7-8**	**Qs 9-10**	**Qs 11-12**	**Qs 13-14**	**Qs 15-16**	**Qs 17-18**	**Qs 19-20**	**Qs 21-22**	**Qs 23-24**
1, 0	8	2	2	16	2	2	8	8	1	13	8	6
0, 1	0	3	1	4	1	6	9	7	0	2	15	8
0, 0	11	30	48	55	68	36	73	13	36	55	22	24
1, 1	85	69	53	29	33	60	14	76	67	34	59	66
Total of 0,1 & 1,0	8	5	3	20	3	8	17	15	1	15	23	14

Sums of the items with 0,1 and 1,0 patterns were drawn at the bottom of the Table 1 which shows high concentrations in questions 7 and 8, 13 and 14, 15 and 16. Also, questions 19 through 24 contained high concentrations of these two patterns. Overall results show a positive trend of correct answers (1, 1) except the group of questions 7-8, 9-10, 13-14, and 19-20. However, these groups also show a consistency in results when reliability was measured through KR-20 formula of overall test. Reliability of the test measure through KR-20 formula was 0.81.

To check the difficulty of items, a graph shown in figure 1 was drawn. The graph shows a dip on questions 13 and 14 while the highest scores were seen for questions 1 and 2.

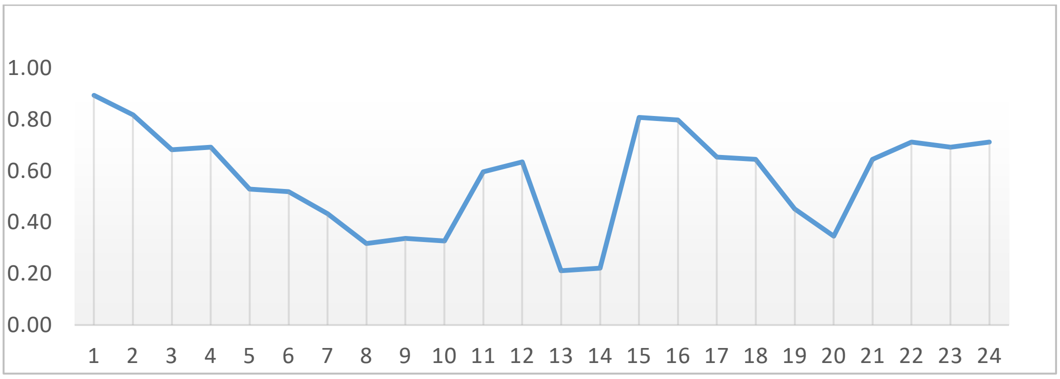

Figure 1. *Average scores of LCTSR*

Content validity was ensured by the teachers teaching science at grade VIII as well as the science education experts. Construct validity of the instrument was ensured using factor analysis. Table 2 shows that six factors were loaded through principal axis factoring by using Varimax with Kaiser Normalization rotation method. Absolute values of small coefficients less than 0.3 were eliminated. It can be clearly seen in table 2 that all the pairs were loaded in the same factor e.g. questions pair 1 and 2 was loaded in factor 4 while questions pair 3 and 4 was loaded in factor 6. Pair of questions 13 and 14 was loaded in factor 1.

Table 2
Factor loading of Lawson's Classroom Test of Scientific Reasoning

Question	Factor					
	1	2	3	4	5	6
Q13	.787					
Q14	.644					
Q17	.820					
Q18	.812					
Q21	.651					
Q22	.832					
Q23	.698					
Q24	.731					
Q9		.916				
Q10		.899				
Q19		.659				
Q20		.838				
Q5			.784			
Q6			.780			
Q7			.858			
Q8			.705			
Q1				.588		
Q2				.838		
Q15				.677		
Q16				.514		
Q3					.912	
Q4					.890	
Q11						.779
Q12						.857

Intervention

A pretest on scientific reasoning and science learning activation was conducted for both groups before the intervention. Experimental group was taught using the HOT instructional model while the students of control group were taught through traditional lecture method. Lessons were planned for 24 weeks for the subject of General Science based on higher order thinking instructional model. These lessons were validated from the science education experts. The duration of the intervention was 24 weeks. After the intervention, a posttest on scientific reasoning and science learning activation was conducted from both groups. Figure 2 below shows the steps/phases involved in HOT instructional model.

A. Engagement

a. Asking critical questions
b. Making comparisons
c. Identifying relationships
d. Formulating problems
e. Estimating the results

B. Investigation

a. Formulating a hypothesis
b. Writing procedures to solve the problem
c. Controlling the variables
d. Measuring
e. Planning

C. Explanation phase

a. Organizing the data
b. Critiquing the data
c. Checking the results
d. Comparing results
e. Identifying assumptions

D. Conclusion Phase

a. Generating ideas
b. Making judgement
c. Expanding on results
d. Defining the concept
e. Producing models

E . Reflection Phase

a. Summarizing results in a graph
b. Evaluating an argument
c. Identifying experimental error
d. Suggesting alternative procedures in solving a problem

Figure 2.*Phases of Higher Order Thinking Instructional Model*

Threats to Internal Validity

Certain threats were to be controlled during the intervention. In general, most of the threats are controlled when we use Quasi Experimental design of the research. Still some measures were taken by the researcher to overcome the threats listed below related to the intervention.

Mortality

There were 37 participants in the experimental group and 40 participants in the control group when intervention was started. Some participants withdrew their admission from the school, or they were absent during the posttest after intervention. At the time of posttest there were only 30 participants in the experimental group and 32 in the control group. The results of 7 participants from experimental group who participated in the pretest were carefully eliminated after matching. Similarly results of 8 participants in the control group who did not participate in the posttest were carefully eliminated after matching.

Testing

Same instrument was used for pretest and posttest which could have caused the participants to be familiar with the test. The intervention period was 24 weeks or 6 months. The students were taught a heavy syllabus of science as well as the other subjects during this time. Weekly tests from the taught content were also taken. This testing of content and the 24 weeks of time between the pretest and posttest minimized the chances of participants being familiar with the test.

Maturation

Both the experimental and control groups spent same amount of time between pretest and posttest. Participants of the experimental group became mature at the same rate as those of control group. Hence the threat of maturation was minimized.

History

Experimental and control groups were the sections of same school and they experienced similar kind of events during the period of intervention. Hence the threat of history was controlled.

Findings and Conclusions

Major objective of this study was to determine the effect of higher order thinking instructional model on scientific reasoning of grade VIII students. Appropriate procedures were used to answer the research questions and to test the hypotheses. This section presents analysis of the data that were collected using the instruments in pretest and posttest from both control and experimental groups.

Level of Scientific Reasoning of Grade VIII Students

Lawson's Classroom Test for Scientific Reasoning was administered to students of both experimental and control groups in pretest and posttest containing 24 items to be marked as true (01) or false (00). Test measured six domains of scientific reasoning. Questions were comprised of pairs i.e., first part of question was about the scientific phenomenon while second part was about to give a reason of that phenomenon.

The subjects of this research comprised of two groups named as experimental and control groups. Experimental group received intervention on Higher Order Thinking while control group was being taught through regular teaching method. The responses of experimental group for Scientific Reasoning in pretest and posttest are as shown in table 3 below.

Table 3

Mean and Standard Deviation of Experimental and Control Groups in Pretest and Posttest Scores of Scientific Reasoning

Group	Test	*n*	*M*	*SD*
Experimental Group	Pretest	30	5.63	2.67
	Posttest	30	8.57	3.97
Control Group	Pretest	32	5.94	2.26
	Posttest	32	6.19	2.71

Table 3 shows that mean (5.63) score of experimental group in scientific reasoning was a little bit lower than the mean (5.94) score of control group in pretest. While mean (8.57) of experimental group was significantly higher than the mean (6.19) of control group in posttest. It shows that the students in experimental group performed better than control group after the intervention in scientific reasoning scores. The mean scores as observed in table 3 suggest values ranging from 5.63 to 8.57.

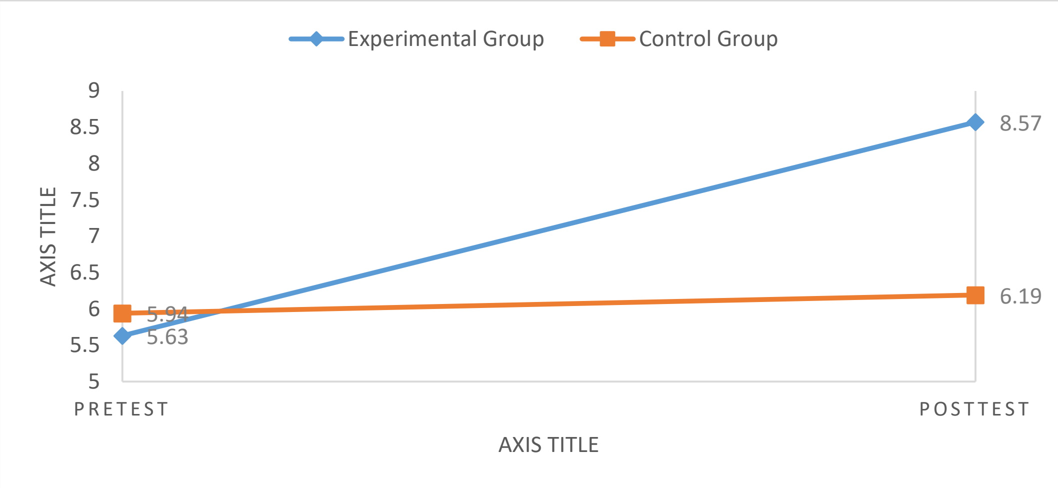

Figure 3. *Comparison of Mean Scores of Experimental and Control Groups in Pretest and Posttest Scores of Scientific Reasoning*

Another scoring system and the determination of the scientific reasoning level refers to the scoring system from Lawson (2004). Learner scan be classified as concrete operational reasoned (score 0-4), transitional reasoner (score 5-8), and reflective or formal operational reasoner (score 9-12). Zulkipli et al. (2019) also used classification of levels as low (0-4), medium (5-8), and high (9-12).

Table 4

Classification of Reasoning Patterns

Test	Reasoning	Level	*n*	Percentage
Pretest	Concrete operational	Low	18	29.03
	Transitional	Medium	37	59.67
	Formal operational	High	7	11.30
Post Test	Concrete operational	Low	9	14.52
	Transitional	Medium	35	56.45
	Formal operational	High	18	29.03

Most of the students lie in transitional reasoning level (37, 59.67% in pretest; 35, 56.45% in posttest). While a shift concrete operational reasoning to formal operational reasoning scores can be observed in Table 4 above.

Higher Order Thinking Instructional Model and Scientific Reasoning

Hypotheses 1, 2, and 3 were developed to measure any effect of higher order thinking instructional model on Scientific Reasoning of grade VIII science students.

Paired samples t-test was applied to test the null hypothesis that there is no significant mean difference between the control group's pretest and posttest scientific reasoning scores of grade VIII science students.

Table 5 below shows the analysis of mean difference between the pretest and posttest scores of control group in scientific reasoning.

Table 5
Mean Difference between Control Group's Pretest and Posttest Scientific Reasoning Scores

Variable	*n*	*M*	*SD*	df	t-value	Significance
Pretest	32	5.94	2.26	31	-0.44	0.66
Posttest	32	6.19	2.71			

Table 5 indicates that t-value (-0.44) is not significant at $p \leq 0.05$ level of significance. So, our null hypothesis "There is no significant mean difference between the control group's pretest and posttest scientific reasoning scores of grade VIII science students" is accepted. Hence it can be concluded that the control group performed at the same level in both pretest and posttest.

Paired samples t-test was applied to test the null hypothesis that there is no significant mean difference between the experimental group's pretest and posttest scientific reasoning scores of grade VIII science students.

Table 6
Mean Difference between Experimental Group's Pretest and Posttest Scientific Reasoning Scores

Variable	*n*	*M*	*SD*	df	t-value	Significance
Pretest	30	5.63	2.67	29	-5.34	0.00
Posttest	30	8.57	3.97			

Table 6 indicates that t-value (-5.34) is significant at $p \leq 0.05$ level of significance, so our null hypothesis "There is no significant mean difference between the experimental group's pretest and posttest scientific reasoning scores of grade VIII science students" is rejected. It is concluded that there is a significant mean difference between the control group's pretest and posttest scientific reasoning scores of grade VIII science students. Further it is evident from table 6that mean (8.57) of posttest was higher than the mean (5.63) of pretest which indicates that students in experimental group performed better in scientific reasoning after the intervention.

Independent samples t-test was applied to test the null hypothesis that there is no significant effect of HOT instructional model on scientific reasoning scores of grade VIII science students

Table 7

Mean Difference between Experimental and Control Group's Scientific Reasoning Scores

Variable	*n*	*M*	*SD*	df	t-value	Significance
Experimental	30	2.93	3	60	3.40	0.001
Control	32	0.25	3.19			

Table 7 indicates that t-value (3.40) is significant at $p \leq 0.05$ level of significance, so our null hypothesis "There is no significant effect of HOT instructional model on scientific reasoning scores of grade VIII science students" is rejected. Hence it is concluded that there is a significant effect of HOT instructional model on scientific reasoning scores of grade VIII science students. Further it is evident from the table 7that mean score (2.93) of experimental group was better than the mean score (0.25) of the control group.

Discussion and Recommendations

Supeno et al. (2019) conducted a study on students' ability to present their higher order thinking skills in physics subject and found that students can reason on a few aspects but still could not satisfy in most of the aspects. They further recommended to createan appropriate instructional design to teach higher order thinking skills. This showed a gap in the body of knowledge. The model was not available in research until Supeno et al. (2019) wrote their article. This study used higher order thinking instructional model developed by Saido et al. (2018) to enhance students' scientific reasoning. The results of this study showed consistency with the results of study conducted Sherriff (2019) in which the researcher employed inquiry-based approaches using higher order thinking that built students' thinking and reasoning skills in a qualitative study.

Scientific reasoning is considered as the part of science learning. The research has found that there is a significant role of students' reasoning ability to predict students' achievement in learning of science (Lawson, Banks, & Logvin, 2007). Students at this stage are to decide which area of study they must opt for future studies which will ultimately decide their career. National Curriculum of Science suggests just to enhance the reasoning ability of students through teaching of science, but no strategy is advised to meet this goal. It is therefore proposed that higher order thinking instructional model therefore be accepted to enhance the reasoning ability of students in National Curriculum of Science as a guide for teachers.

It is recommended that teachers should develop their lessons based on levels and they should not try to achieve all the objectives in a single period. Textbook should not be the only source of reference for a teacher as it encourages rote memorization. Assessment of students should be based on the goals of teaching science along with the objectives or learning outcomes. This may require from the examiners to add a general question regarding students' learning as were set in the aims of curriculum. Similarly, students and teachers may also be informed and reminded the criteria time to time on which students are going to be assessed at the end of year. A comprehensive training plan regarding the use of higher order thinking instructional model may be devised for the in-service teachers as well as for the pre-service teachers.

Finally, due to the same locality and same background of the respondents, it was not possible to study any variation in demographics e.g., the respondents were from same age group (14-15 years), same gender, parents of the respondents were from same socioeconomic background (shopkeepers, daily wagers), and almost same parental qualifications etc. Also, an insight from the students can be sought through observations and some interviews. For future researchers it is, therefore, recommended that a qualitative research can be followed up to get an in-depth insight of the phenomena.

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