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Scope for Higher Order Thinking Through Mathematics Instructions

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Abstract: Learning theories that evolved from the behaviourist, cognitivist and the constructivist paradigm, when applied in mathematics classroom with appropriate teaching strategies, lead to lower and higher order thinking skills in students. In the present study, the investigator developed an Instructional package for the mathematics topic 'Real numbers' of the class IX level. The package was mainly structured with constructivist strategies like generalization, visualization and estimation along with cognitivist teaching strategies for concept clarity. It was implemented by the investigator on class IX students of the GSHSEB school, India. The same topic was taught to a statistically equated Control group by the conventional method. T-test was used to compare the pretest and the posttest scores for each of the levels – comprehension, application, analysis, synthesis and evaluation for the Control and the Experimental group. A significant difference in the mean for all the levels except for the evaluation level, was observed in the Experimental group.

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I. INTRODUCTION

The structure of teaching begins with planning. The basic crux of any Lesson Plan are the specific objectives which enunciate the expected learning outcomes from the students. Thus, the main aim of teaching is to cause effective learning. While teaching, the content that is transmitted by one individual can be received by another, only if the contents are passed on through specific mental pathways that are open or functional in the receiver or the learner. Thus, between the input (teaching) and the output (learning), mental processes (thinking) of the learner may stand as a barrier or a support. The process of thinking is a fluid mechanism resulting into evolving structures due to unique amalgamations of knowledge, experiences and myriad interpretations (Smith, & Kosslyn, 2008). The same content being taught by one teacher is processed differently by every learner. Thus, the mental processes of thinking and learning are very strongly interconnected to each other. Learning theories have been conceptualized and concretized after in depth study of thinking processes.

Learning theories that evolved from the Behaviourist paradigm (Stimulus-Response theories) led the school curriculum to devise teaching strategies like drill or rote work, repetitive practice, use of incentives, verbal reinforcements, establishment of rules (Kelly, 2012). These strategies are invariably used even in today's mathematics classrooms to help students remember multiplication tables, mathematics formulae, definitions, algorithms for basic maths and all other tasks that need memorizing. Thus, the behaviourist paradigm proved its relevance in habit formation, peripheral intermediaries and trial and error mechanisms as learning outcomes but limits its application only to the development of memory muscles within the cognitive structures (Hilgard, 2011).

The Cognitivist theories that evolved in the early twentieth century gave prominence to mental processes rather than the observable behaviour. Cognitive learning theorists believe that learning occurs through internal processing of information and involves the reorganization of experiences, either by attaining new insights or changing old ones. Inclusion of the cognitivist paradigm in education resulted into teaching strategies in mathematics classroom like classifying or chunking information, linking concepts or new content to previously known ones, providing structure or designing the lesson in efficient and meaningful ways, using real world examples, conducting discussions, problem solving, using analogies, providing visuals, using mnemonics (Kelly, 2012). These teaching strategies are prominent contents of teacher education curriculum in India (NCF, 2005). Effective dissemination of these strategies results into conceptual clarity, procedural knowledge and application of content under similar contexts, among learners. But the cognitivist paradigm needs an extension to cater to the twenty first century learning requirements. With the technological revolution dominating this generation, higher mental skills like analysis, synthesis, evaluation and creation are expected to be developed among learners. Thus, constructivism paradigm is an extension of cognitivism.

Constructivism which takes shape from the Functionalism psychology (John Dewey) is based on the premise that every individual construct their own perspective of the world based on their experiences and their previous knowledge (Hilgard, 2011). This suggests inconsistency in learning outcomes as every individual is unique in terms of absorption, processing and interpretation of knowledge. Integration of constructivism with school curriculum resulted into teaching strategies like use of case studies, research projects, problem-based learning, brainstorming, collaborative learning, discovery learning, simulations (Kelly, 2012). These strategies clearly cater to the higher aims of education which is the development of the inner resources of the child apart from providing them employable skills (NCF, 2005).

The aim of Mathematics as a subject is the development of mathematical thinking that pursues clarity of thought, uses logical reasoning to justify logical conclusions, visualizes and concretizes abstractions (NCF, 2005). This aim can be fulfilled by integrating the teaching strategies of all the above paradigms. The behaviourist strategies delivered in isolation can cause only 'knowledge' level learning; whereas together with cognitivist strategies it can cater to the 'comprehension' and the 'application' level learning as well. Both the strategies if topped up with constructivist strategies can cause higher levels of learning that utilizes the mental skills of 'analysis, synthesis, evaluation and creation'.

Higher-Order-Thinking-Skills in Mathematics

NCF 2005, Position paper, Teaching of Mathematics, proposed pedagogical processes like formal problem solving, use of heuristics, estimation and approximation, generalisation, visualisation, representation, reasoning and proof, making connections, mathematical communication to satisfy the goal of developing mathematical higher order thinking skills (HOTS) among students. But since HOTS cannot be developed without a strong foundation of conceptual and procedural knowledge which needs LOTS (Lower order thinking skills); every mathematics topic need a well-integrated lesson plan with teaching strategies that cater to all the skills - knowledge, comprehension, application, analysis, synthesis and evaluation.

A more specific description of higher order thinking skills is provided by the Bloom's Taxonomy. According to which, skills involving Application, Analysis, Synthesis and Evaluation are of a higher order. 'Application' is the ability to use information, methods, concepts, theories in familiar situations and solve problems using required skills or knowledge. 'Analysis' is the ability to see patterns, organize parts, recognize hidden meaning and identification of components. 'Synthesis' is the ability to use old ideas to create new ones, generalize from given facts, relate knowledge from several areas, predict and draw conclusions. 'Evaluate' is the ability to compare and discriminate between ideas, make choices based on reasoned argument and verify value of evidence (Collins, 2014).

Teaching Strategies – Generalization, Estimation and Visualization

By integrating strategies like generalization, visualization and estimation apart from the other strategies propagated by the cognitivist paradigm in mathematics classrooms, students get a scope to exercise their analysis, synthesis and evaluation skills. But the teachers of school and university hardly pay attention to these skills. These methods are neglected in mathematics teaching and math problem solving process (Hashemi, Abu, Kashefi, Rahimi, 2013). If the same is used profusely in mathematics teaching right from elementary to higher secondary level, learners develop higher order thinking skills and are able to extend and transfer mental knowledge to practical knowledge.

In case of mathematics, Sriraman (2004) defines Generalization as 'the process by which one drives or induces from particular cases'. Generalization can thus be considered as teaching strategies that are designed to engage students into inductive reasoning i.e. to observe or work with given set of data, analyse it in the process and identify the pattern or the relationship that exists within the components and synthesize them to infer a mathematical rule, property, law, formula or definition (Yilmaz, Argun & Keskin, 2009). Mason (2012) introduced processes in his framework to help students generalize, which included(1) specialization (2) conjecturing (3) symbolization and (4) generalization, with an emphasis to be systematic in specialization (Mason, Burton, & Stacey, 2010).

For example, if the aim is to allow the students to identify the properties of 'Irrational Numbers', specialization would involve the teacher to guide the students to compute the decimal values of square roots of 2 to 20. Probe the students to observe and make a conjecture that the square roots of non-perfect-squares result into non-terminating-non-recurring decimals and the square roots of perfect squares result into terminating decimals. Students can be explained that the same holds true for non-perfect cubes, fourths etc. and thus made to symbolize '$\sqrt[n]{a}$ is an Irrational number for $n \in N$, $n > 1$ and $a \in Q$ and is a non-perfect root of n'. Similarly, students are guided to compute and observe that all kinds of fractions result into either terminating or recurring decimals. The only kind of decimals that cannot be converted back to fractions (rational numbers) are the non-terminating-non-recurring ones. Thus, this kind of systematic specialization can lead students to generalize the properties of Irrational Numbers - the non-terminating-non-recurring decimal numbers are Irrational numbers; Square roots of non-perfect squares/cube roots of non-perfect cubes/.. are irrational numbers; all the numbers that are not Rational numbers are Irrational numbers.

Estimating and Approximating are vital skills that need to be imbibed in students by mathematics educators so that they can handle the ever-increasing complexities of the real world. ‘Estimating a desired quantity’ involves making a judgment based on very general consideration – in contrast to finding the exact quantity. ‘Approximation’ is an attempt to come to a larger value which can be approached as closely as desired. These competencies become invaluable as the student elevates from primary to the secondary and further to the higher secondary levels where mathematical contents also ascend from concrete to abstract (Thompson 2010).

Similarly designing instructions that cater to the development of the ‘Visualizing’ skill treads the mind towards higher-order thinking. ‘Visualizing means summoning up a mental image of the content in hand to understand it better. The image may be of some geometrical shape, or of a graph or diagram, or it may be some set of symbols or some procedure’ (Open University, 1988, p.10). The basic ideas of mathematics – order, distance, operations with numbers etc. – are born from concrete or visualizable situations. Even while dealing with abstract ideas, mathematicians need to explore the corresponding concrete ideas. This exploration can be termed as mathematical visualization. Majority of the mathematics content at the secondary and higher secondary levels need students to carry out Isomorphic visualization. In which, the process begins at a concrete level, moving gradually toward the respective abstract connections and further towards generalizing and manipulating the abstract dimensions (Guzman, n.d.).

The teaching strategies used for ‘estimation’ and ‘visualization’ can be exemplified using the same concept of Irrational numbers as above. Students can be guided to place the decimal values of square roots of 1 to 20 on a Number line to concretize the otherwise abstract concept of irrational numbers. Students analyse the relationship of Irrational numbers with integers by visualizing the pattern apparent from the decimal values of $\sqrt{1}$ to $\sqrt{20}$. This visualization further helps students tosynthesize (1) the knowledge regarding the place of every Irrational number with respect to Rational numbers on the Number line; and (2) the infinite status of the set of Real numbers not only while we move from zero to the positive and the negative directions but also in between any two given Real numbers.

The strategy of ‘Estimation’ can be used by the teacher by probing students to find the place of an Irrational number on the Number line. Students use the mental skill of analysis when they estimate the numerical decimal value of a given non-perfect square root and state its position with respect to nearby Integers.

For example,$\sqrt{2}$ lies between 1 and 2 (=$\sqrt{4}$), so the value of $\sqrt{2}$ has to be 1 with a non-recurring decimal part. This also helps student to estimate the position of $\sqrt{2}$ on the Number line. This kind of analysis that the student does helps him to synthesize his knowledge to predict the decimal value and the position of any other larger Irrational number (square root of non-perfect square). If students are asked to explain and verify their conjectures with proper reasoning, they get a scope to exercise their evaluation skill.

The investigator raised the following Research Questions in the present Study :

1. Can Lesson plans be created that includes teaching strategies like generalization, visualization and estimation (HOTS strategies) well assimilated with other cognitivist strategies for mathematics topics at school level?
2. Is effective implementation of these HOTS strategies possible in mathematics classrooms of India?
3. Can such strategies really develop higher order thinking skills in students?
4. How effective are these strategies in increasing the mathematics achievement among students?
5. How do students respond to HOTS strategies being used in their classrooms?

In order to respond to these questions, the investigator developed an Instructional package which included twenty-five lesson plans on the topic ‘Real Numbers’ for IX standard students. It also included eighteen worksheets, two self-learning materials and power point presentations. An experimental study was conducted, where the package was implemented by the investigator on thirty-three students of the Experimental group. An equivalent group consisting of thirty-one students was taken as the Control group which was taught the same topic by the Conventional method by the regular teacher. A pretest and a posttest was made by the investigator of sixty marks each that included three questions of the comprehension, application, analysis, synthesis and evaluation levels each. The posttest scores of each of the levels were compared for the Experimental and the Control group by t-tests for each level. Also, the pretest and the posttest scores for all the levels were separately compared for each the Experimental and Control group. The procedure, data analysis and findings of the study are elaborated further.

II. METHODOLOGY OF THE STUDY

A. Statement of the Problem

The Effectiveness of an Instructional Package on the content-specific higher order thinking skills of students in mathematics

B. Objectives of the Study

1) To develop an Instructional package in Mathematics for standard IX students studying in schools affiliated to GSHSEB (Gujarat State Secondary and Higher Secondary Education Board).

2) To implement the Instructional package on standard IX students.

3) To study the effectiveness of the Instructional package on the acquisition of content-specific higher-order thinking skills in standard IX students.

C. Explanation of Terms

Instructional Package:

Instructional materials like lesson plans, worksheets, self-learning materials, power point presentations, and assessment sheets assembled to transact teaching through cognitivist strategies and specially integrated with the generalization, visualization and estimation strategies.

Content-specific higher order thinking skills:

Thinking skills like Application, Analysis, Synthesis, Evaluation (Blooms taxonomy) specific to the topic 'Real Number' at the IX^{th} standard level.

D. Hypotheses of the Study

H_0: There is no significant difference between the Mean Achievement scores of the students exposed to Instructional Package and the Conventional Method with respect to the Specific Objectives like Comprehension, Application, Analysis, Synthesis and Evaluation.

E. Delimitation of the Study

The present study was delimited to standard IX English Medium GSHSEB students and only for the content 'Real Numbers' of the mathematics textbook in the year 2017.

F. Design of the Study

The Study adopted the Pretest Posttest Equivalent Group design.

G. Population of the Study

The population of the study consisted of all the standard IX English Medium students of GSHSEB of Vadodara city in the year 2017. There are 65 grant-in-aid schools in the city of Vadodara, functioning under the Gujarat State Board of Secondary and Higher Secondary Education Board (GSHSEB) following the rules and regulations laid by the Ministry of Human Resources of the Government of India.

H. Sample and Procedure of the Study

Seventy two IX standard students of one English medium school of Vadodara following the GSHSEB syllabus was selected purposively as sample for the Study. The Experimental Group consisted of 36 students and the Control Group consisted of 36 students. The Experimental Group studied through the Instructional Package and the Control Group studied through the Conventional method. Students in both the groups learned the same topic viz 'Real Numbers' through respective instructional strategy. Experiment time was 42 sessions of 35 minutes in each group.

I. Tools for Data Collection

1) Instructional package developed by the investigator and modified according to the advice given by experts in Mathematics, Mathematics Education and English.

2) Achievement tests developed by the investigator for the Pretest and Posttest. Both the tests were of 60 marks each, with three questions of 4 marks each of the comprehension, application, analysis, synthesis and evaluation levels. The questions were framed as per the criteria mentioned in Bloom's taxonomy in Collins (2014) and can be described as HOTS questions as they were non-algorithmic, effortful, involved nuanced judgments and application of multiple criteria (National Research Council, 1987).

J. Steps in Data Collection

Step 1: One of the English medium school of Vadodara, India following GSHSEB syllabus standard IX students were selected purposively based on the permission granted by the school.

Step 2: Class VIII final examination mathematics marks were collected by the investigator to statistically equate the Experimental and the Control group.

Step 3: Randomly one of the group was selected as the Experimental group and the other as the Control group. The Pretest was administered both to the Experimental and the Control groups.

Step 4: The Control group was taught by the usual Conventional method by the regular school teacher and Experimental group by the Instructional package made by the investigator.

Step 5: Students were taught in their respective methods till the completion of the selected unit 'Real Numbers'.

Step 6: Posttest was administered to the students of both the groups.

Step 7: The responses of the Pretest and Posttest were scored and analyzed.

III. DATA ANALYSIS AND INTERPRETATION

1. Comparison of the Control and Experimental groups on Achievement in Mathematics on Posttest with respect to the Specific Objectives - Comprehension, Application, Analysis, Synthesis, Evaluation using 't' test:

The difference between the Mean Achievement scores on Posttest of the Control group and Experimental group with respect to specific objectives like Comprehension, Application, Analysis, Synthesis and Evaluation is presented in table 1.

Table 1: Difference between the Mean Achievement Scores on Posttest of the Control group and Experimental group with respect to Specific Objectives

Objective	Group	Mean	SD	df	t	Sig. (p-value)	Remarks
Comprehension	Control	3.47	2.66	31	3.20	0.002	S
	Experimental	5.83	3.26	32			
Application	Control	1.33	1.43	31	3.84	0.000	S
	Experimental	3.03	2.07	32			
Analysis	Control	1.13	1.42	31	3.09	0.003	S
	Experimental	2.56	2.22	32			
Synthesis	Control	1.13	1.11	31	2.00	0.04	S
	Experimental	1.82	1.62	32			
Evaluation	Control	0.33	0.96	31	1.56	0.12	NS
	Experimental	0.71	1.03	32			

Table 1 shows that for the Specific Objective – Comprehension, the obtained 't' value 3.20 is greater than the table value 1.96 at 0.05 level ($p<0.05$); for the Specific Objective – Application, the obtained 't' value 3.84 is greater than the table value 1.96 at 0.05 level ($p<0.05$); for the Specific Objective – Analysis, the obtained 't' value 3.09 is greater than the table value 1.96 at 0.05 level ($p<0.05$) and for the Specific Objective – Synthesis, the obtained 't' value 2.00 is greater than the table value 1.96 at 0.05 level ($p<0.05$). So, there is a significant difference between the Control group and the Experimental group students in their Mean Achievement scores on Posttest with respect to the Specific Objectives – Comprehension, Application, Analysis and Synthesis. For the Specific Objective – Evaluation, the obtained 't' value 1.56 is less than the table value 1.96 at 0.05 level ($p>0.05$) and so there is no significant difference between the Control group and the Experimental group students in their Mean Achievement scores on Posttest with respect to the Specific Objective – Evaluation. Thus, the null hypothesis was rejected at he significance level 0.05 for specific objectives Comprehension, Application, Analysis and Synthesis and was accepted for the specific objective of Evaluation.

2. Comparison of the Experimental group on Achievement in Mathematics on Pretest and Posttest with respect to the Specific Objectives - Comprehension, Application, Analysis, Synthesis, Evaluation using 't' test:

The difference between the Mean Achievement scores on Pretest and Posttest of the Experimental group with respect to Specific Objectives-Comprehension, Application, Analysis, Synthesis and Evaluation is presented in table 2 (attached).

Table 2: Difference between the Mean Achievement Scores on Pretest and Posttest of the Experimental group with respect to Specific Objectives

Specific Objectives	t-value	p-value	Remark
Comprehension	3.24	0.002	S
Application	8.14	0.000	S
Analysis	5.98	0.000	S
Synthesis	5.72	0.000	S
Evaluation	1.94	0.06	NS

Table 2 indicates that for the Specific Objective – Comprehension, the obtained 't' value 3.24 is greater than the table value 1.96 at 0.05 level ($p<0.05$); for the Specific Objective – Application, the obtained 't' value 8.14 is greater than the table value 1.96 at 0.05 level ($p<0.05$); for the Specific Objective – Analysis, the obtained 't' value 5.98 is greater than the table value 1.96 at 0.05 level ($p<0.05$) and for the Specific Objective – Synthesis, the obtained 't' value 5.72 is greater than the table value 1.96 at 0.05 level ($p<0.05$). So, there is a significant difference between the achievement scores of the Pretest and Posttest of the Experimental group students with respect to the Specific Objectives – Comprehension, Application, Analysis and Synthesis. For the Specific Objective – Evaluation, the obtained 't' value 1.94 is less than the table value 1.96 at 0.05 level ($p>0.05$) and so there is no significant difference between the Pretest and Posttest achievement scores of the Experimental group students with respect to the Specific Objective – Evaluation.

3. Comparison of the Control group on Achievement in Mathematics on Pretest and Posttest with respect to the Specific Objectives - Comprehension, Application, Analysis, Synthesis, Evaluation using 't' test:
The difference between the Mean Achievement scores on Pretest and Posttest of the Control group with respect to Specific Objectives like Comprehension, Application, Analysis, Synthesis and Evaluation is presented in table 3.

Table 3: Difference between the Mean Achievement Scores on Pretest and Posttest of the Control group with respect to Specific Objectives

Specific Objectives	t-value	p-value	Remark
Comprehension	3.11	0.003	S
Application	0.70	0.48	NS
Analysis	1.39	0.17	NS
Synthesis	0.24	0.80	NS
Evaluation	0.62	0.53	NS

Table 3 shows that for the Specific Objective – Comprehension, the obtained 't' value 3.11 is greater than the table value 1.96 at 0.05 level ($p<0.05$) so there is significant difference between the Pretest and Posttest achievement scores of the Control group students with respect to the Specific Objective – Comprehension. For the Specific Objective – Application, the obtained 't' value 0.70 is less than the table value 1.96 at 0.05 level ($p>0.05$); for the Specific Objective – Analysis, the obtained 't' value 1.39 is less than the table value 1.96 at 0.05 level ($p>0.05$) and for the Specific Objective – Synthesis, the obtained 't' value 0.24 is less than the table value 1.96 at 0.05 level ($p>0.05$); for the Specific Objective – Evaluation, the obtained 't' value 0.62 is less than the table value 1.96 at 0.05 level ($p>0.05$) and so there is no significant difference between the Pretest and Posttest achievement scores of the Control group students with respect to the Specific Objective – Application, Analysis, Synthesis and Evaluation.

IV. FINDINGS

The results indicate that the students exposed to the Instructional Package performed better in achievement test that focused on questions requiring higher order thinking abilities, than that of the students exposed to the Conventional Method with respect to the Specific Objectives – Comprehension, Application, Analysis and Synthesis. For the Specific Objective – Evaluation, the students exposed to Instructional Package performed better in achievement test that focused on questions requiring higher order thinking abilities, than the students who were exposed to Conventional Method, but not significantly. Overall the relative achievement of the Experimental group was better than the Control group.

The students performed better in the Comprehension, Application, Analysis and Synthesis level questions after being exposed to Instructional package. The students who were exposed to the Conventional method of teaching could perform better only on the Comprehension level objectives. On the whole, the instructional package that included teaching strategies like generalization, visualization and estimation was successful in developing content-specific higher-order-thinking-skills like Application, Analysis and Synthesis among students with respect to the content 'Real numbers'.

V. EDUCATIONAL IMPLICATION OF THE PRESENT STUDY

The effectiveness of the developed Instructional Package in terms of higher order thinking skills specifically for the concepts of Real Numbers indicate further implications of the teaching strategies used in the Package. All the Mathematics topics of the secondary section can be designed using similar teaching strategies so that teaching-learning can produce learning outcomes as envisaged by the NCF and as per the needs of the evolving generation.

VI. CONCLUSION

Development of higher order thinking skills in students, need teacher-expertise in content, pedagogical practices, and a good knowledge of students' mathematical thinking processes. Instructions in the classroom need to be well planned and structured around the parameters that have proved to be successful in promoting higher-order thinking skills in students and an affective climate need to be maintained. Integrating the pedagogical practices with the content matter and then transacting the same in the classroom is a challenge for the mathematics teachers who are conditioned to disseminate knowledge in the traditional mode , thus the Instructional package that include lesson plans designed with content matter integrated with the above strategies that focus on conceptual understanding and use of skills like estimation, generalization, visualization can be a guiding literature for mathematics teachers who aspire to develop higher order thinking skills in their students

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