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Effectiveness of STEM Approach on Enhancing Critical Thinking Skill of Secondary School Students

Noufal P

Research Scholar, Department of Education, Regional Institute of Education (NCERT), Mysore-570006

Corresponding Author:** ***Noufal P, *Research Scholar, Department of Education, Regional Institute of Education (NCERT), Mysore-570006*

Abstract: *This study aimed to investigate the Effectiveness of Science-Technology-Engineering-Mathematics (STEM) Approach in Enhancing Critical Thinking Skill among Secondary School Students. This study used Pre-and Post-test experimental and control group design in a quasi experiment setting. Pre test and post test were given to both experimental and control group. In this study, experimental group is provided an experimental treatment i.e., teaching through STEM approach and the control group teaching through traditional method of teaching science. This study involved students of 9th standard in two government schools of Malappuram District, Kerala. Tool used in the study was the Malayalam version of Watson-Glaser Critical Thinking Appraisal prepared and standardized by the researcher. Descriptive statistics such as Mean, median, mode, standard deviation, skewness and Kurtosis were used to analyze the nature of the distribution of the scores of dependent variable. Independent sample t-test, paired sample t-test, Two way ANOVA and ANCOVA were used to find out the effectiveness of the experimental treatment on the dependent variable. STEM approach based teaching was more effective in developing critical thinking skill among the secondary school students. Experimental group was found to be benefited more than the control group with respect to development of critical thinking ability. Science textbooks should be modified based on the requirement of STEM approach of teaching. It could be better if they include various day to day life applications of the scientific content, designing of various applications.*

Keywords: *STEM Approach, Critical thinking skill, Secondary school students.*

1. INTRODUCTION

Among the 21st century issues and trends in science education, one must acknowledge the fundamental importance of the science curriculum. Science teaching should consist of coordinated and systematic strategies that provide opportunities to learn for a diversity of students. Best example of such teaching is 5E model used is Biological Sciences Curriculum Study (BSCS) materials that provide students opportunities and time to learn. Content knowledge can have a positive influence on student achievement especially in secondary science (Whitehurst 2002). Students achievement in science has been found to be strongly related to teacher's preparation in both subject matter and teaching methods, as well as to their preparation to work with diverse students (Goldhaber and Brewer 2000; Wenglinsky 2002). To improve student achievement in science, the curriculum and supplying textbooks is important. Student's enthusiasm for science can be shaped by teacher attitude. Successful teachers provide a learning environment in which curiosity is encouraged openly and students have opportunities to explore ideas and physical objects. Accomplished teachers use a variety of instructional approaches to guide learners toward knowledge about the natural world and about how science, as a discipline, gathers knowledge and condenses knowledge about the world. Since the needs and interests of each learner are unique, it is important to provide different kinds of opportunities for students to experience the natural world and test and refine their conceptual frameworks. (Nancy P Moreno, Barbara Z.Tharp). In the 21st century, education has become most importance because we must ensure that students have the skills to learn, to innovate and to use technology and information for making a better living condition. The development of Science and Technology has become a part of every aspect of modern life. One of the valuable assets of a country is to educate the people and workforce which is established through a good educational system so that they are not only able to accept and adapt to the rapid changes of time, but also can play an active role to form a better future for the society that they are living.

STEM Education is defined as an educational system creating connections in the disciplines of Science, Technology, Engineering and Mathematics and application-oriented approaches (Bybee, 2010). STEM education provides opportunities for students to be able to solve problems, to be innovators, inventors, logical thinkers and technologically literate (Morrison, 2006; Stohlman et al., 2011). In STEM education, there are many facets to discuss and flesh out, appear to discuss it one of three ways: (a) instructionally (b) as a set of integrated or interconnected disciplines, or (c) as more dependent on the stakeholders or context in which it is viewed or conceptualized.

Pertaining to pedagogy, Johnson (2013) defines it as "an instructional approach, which integrates the teaching of science and mathematics through the infusion of the practices of scientific inquiry, technological and engineering design, mathematical analysis, and 21st century interdisciplinary themes and skills".

The development of STEM-based learning design can be carried out on science learning by incorporating STEM characteristics without changing the curriculum itself. The development of STEM-based science learning can be started by developing the learning descriptions embodied in syllabus, lesson plans, worksheets, modules, assessments, etc.

In the learning of physics, the goal is to produce competent problem solvers (Ding, Reay, Lee, & Bao, 2011), who use higher-order thinking skills that become the central component of the learning of physics (Docktor & Mestre, 2014).

A central goal of science education is to teach students to think critically about scientific data and models. There were many indications of how difficulty is for people to master this type of thinking, as evidenced by many societal debates. Although teaching quantitative critical thinking is a fundamental goal of science education, particularly the laboratory portion, the evidence indicates this is seldom, if ever, being achieved Critical Thinking involves the ability to clearly and precisely raise vital questions, gather relevant information and reach well-reasoned conclusions, make accurate decisions, assess the credibility of sources, identify cause-effect relationships, and effectively communicate with others in figuring out solutions (Ennis 1989; Halpern 1993)

Research found that critical thinking is a skill needed to function well in the 21st century. It was also found that critical thinking helps students to learn to think clearer, to ask questions in classroom and in community at large, and to become better students, indivisible, and members of society (Mabe, 2004). Critical thinking is beyond a predictive measure to academic performance. As it suggests open-mindedness, critical thinkers allow themselves to take risks and venture themselves in various options. Critical thinkers make evaluations on options before making decisions. In every situation, critical thinking plays an important role in day-to-day functioning

2. Need And Significance

In various educational researches, it has found that the quality of instructional practices employed by teachers has an impact on students' engagement with the content and their level of achievement.

STEM approach is very useful for enhancing students' learning achievements and assessing critical thinking and solving problem skills in Physics class at the 11th grade level (A. Tungsom batsanti, K. Ponkham, and T.Somtoa, 2018). Skills such as inquiry, creativity, critical and analytical thinking and decision making are some of the attributes that are sought in qualified individuals. Nampetch Kakarndee, Nukool Kudthalang, Natchanok Jansawang (2018), found that there was a positive effect on developing creative thinking ability and learning achievement based on STEM approach. So in the present study, researcher felt that there is a need for conducting an experimental research to study the effectiveness of STEM approach on developing the higher order thinking skills in the Indian scenario.

3. Research Question

What is the effect of 'STEM approach' of teaching Science in developing critical thinking skill among Secondary School Students?

4. Objectives

1. To compare the mean pre-test scores of Critical thinking skill between Experimental and Control Group for the selected sample
2. To compare the mean post-test scores of Critical thinking skill between Experimental and Control Group for the selected sample

3. To compare the mean gain scores of Critical thinking skill between Experimental and Control Group for the selected sample
4. To study the Effectiveness of STEM Approach on developing the Critical thinking skill among Secondary School Students.

5. HYPOTHESES

1. There is no significant difference in the mean pre-test scores of Critical thinking skill between experimental and control group
2. There is no significant difference in the mean post-test scores of Critical thinking skill between experimental and control group
3. There is no significant difference in the mean gain scores of Critical thinking skill between experimental and control group
4. The Critical thinking ability of the experimental group who will be taught through 'STEM approach' will be significantly higher than that of the control group taught through traditional approach of teaching science.

6. VARIABLES

In the present study, two methods of teaching ('STEM Approach' based teaching of science and traditional approach of teaching science) was considered as Independent variables, Critical thinking ability was considered as Dependent variable.

7. OPERATIONAL DEFINITIONS

Science-Technology-Engineering-Mathematics (STEM) approach: In this study, STEM Approach means the teaching of scientific contents through integrating Technology, Engineering and Mathematics concepts.

Traditional approach of teaching science – In this study, traditional approach of teaching science means the teaching approach where the teacher is the focus of the learning environment and gives major importance to the text book contents.

Critical thinking skill: The present study defines critical thinking as the ability of a person to expand his knowledge on a problem or situation through Inference, Recognition of Assumptions, Deduction, Interpretation and Evaluation of Arguments.

In the present study, Critical thinking ability is the score obtained by the students in the Watson-Glaser Critical Thinking Appraisal

8. METHODOLOGY

In this study, researcher has selected a group of students from secondary level of two different schools of the same categories, facilities, etc. of the same area. One group of students has taught through STEM approach (Experimental group) by the researcher, and the other group of students through traditional approach of teaching science (Control group) by the regular school subject teacher. The lessons were taught to both experimental and control group simultaneously. Before the treatment pre-test was conducted in order to understand the level of the students. Here the two groups of students were selected through convenient sampling technique. The current study was based on, quasi-experimental design in nature, because of the nature of selection of experimental and control group. The topics for the treatment were selected from the Physics lessons at the secondary level text book of Kerala state. After the treatment the post test was conducted in order to find the effectiveness.

To assess the Critical thinking Skill, the Malayalam version of Watson-Glacer Critical Thinking Appraisal was constructed by the researcher. The Cronbach's alpha reliability coefficient of the tool was 0.756.

9. STATISTICAL TECHNIQUES

Both Descriptive statistics and Inferential Statistics have used for the data analysis. Descriptive statistics such as Mean, median, mode, standard deviation, skewness and Kurtosis were used to analyze the nature of the distribution of the scores of dependent variables. Independent sample t-test,

paired sample t-test, Two way ANOVA and ANCOVA were used to find out the effectiveness of the experimental treatment on the dependent variable.

10. Research Design

This study used Pre-and Post-test experimental and control group design in a quasi experiment setting was adopted. Pre test and post test were given to both experimental and control group. In this study, experimental group is provided an experimental treatment i.e., teaching through STEM approach and the control group through traditional teaching of science.

Table1. *Research design of the study*

Group	Pre test	Treatment	Post test
E	Y1	X	Y2
C	Y1	-	Y2

Where E means Experimental Group; C Means Control Group; X means Treatment

Watson and Glaser Critical thinking appraisal

The Watson-Glaser Critical Thinking Appraisal (WGCTA), is designed to measure important abilities involved in critical thinking. A major goal of academic instruction, critical thinking ability also plays a major role in many occupations. WGCTA is composed of five subtests such as Inference, Recognition of Assumptions, Deduction, Interpretation and Evaluation of Arguments.

Researcher had prepared the Malayalam version of the WGCTA with the help of the Malayalam subject experts and the internal consistency of the Malayalam version of the tool was measured. The Cronbach's alpha coefficient of this tool was 0.756.

11. Data Analysis And Interpretation

In the present study, researcher has taken the mean scores obtained in pre test; post test and gain score for the statistical analysis. The analysis of data was presented below:

Comparison of the mean pre-test scores of Critical thinking skill between Experimental and Control Group

In the present study, investigator administered Critical thinking skill test as a pre test tool to find out the effectiveness of the experiment. The mean and standard deviation of the pre-test scores of both the experimental and control group were found out and tested the significance of difference between these two means. The difference of the mean pre-test scores between the experimental and the control groups were tested using independent sample t-test and the result is given in the Table (2) below.

Hypothesis 1: There is no significant difference in the mean pre test scores of critical thinking skill between experimental and control group for the selected sample

Table2. *Mean pre test score, SD, std. error of mean, t-value of experimental and control group*

Pre critical thinking skill score	Group	N	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-tailed)	Remarks
	Experimental	47	18.0426	3.70051	.53978	-.694	0.490	P>0.05 Not Significant
	Control	39	18.5897	3.56679	.57114			

From the table (2), it is clear that the critical ratio obtained is not significant at 0.05 level of confidence. This shows that there is no significant difference of the mean pre-test scores on Critical thinking skill between Experimental and control groups. Hence the null hypothesis was accepted. It means that both the experimental and control group do not differ significantly in their pre test mean scores. So it can be inferred that both the groups have almost similar scores in Critical thinking skill.

Comparison of mean post-test scores of Critical thinking skill between Experimental and Control Group

Researcher administered Critical thinking skill as a post test tool to find out the effectiveness of the experiment. The mean and standard deviation of the post-test scores of both the experimental and

control group were found out and tested the significance of difference between these two means. The difference of the mean post-test scores between the experimental and the control groups were tested using independent sample t-test and the result is given in the Table (2) below:

Hypothesis 2: There is no significant difference in the mean post test scores in Critical thinking skill between experimental and control group for the selected sample

Table3. *Mean post test score, SD, std. error of mean, t-value of experimental and control group*

Post critical thinking skill score	Group	N	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-tailed)	Remarks
	Experimental	47	21.5106	4.32321	.63060	1.252	0.214	p>0.05 Not Significant
	Control	39	20.4615	3.44770	.55207			

From the above table (3) it is clear that the calculated t value is 1.252 which is less than 1.96 and 2.58. That means the critical ratio is not significant at both the levels of significance. This shows that there is no significant difference of the means of post test scores of Critical thinking skill between experimental and control groups. Hence the null hypothesis was accepted.

Comparison of mean gain scores of Critical thinking skill between Experimental and Control Group

The mean gain scores of both the experimental and control groups were compared to test the significant difference in Critical thinking skill. The data and the results of test of significance of the mean gain scores in Critical thinking skill are given in the table (4).

Hypothesis 3: There is no significant difference in the mean gain scores in critical thinking skill between experimental and control group

Table4. *Mean gain score, SD, std. error of mean, t-value of experimental and control group*

Gain critical thinking skill score	Group	N	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-tailed)	Remarks
	Experimental	47	3.4681	2.48343	.36225	3.198	0.002	P<0.05 Significant
	Control	39	1.8718	2.06703	.33099			

From the table (4) it is clear that, the critical ratio obtained is significant at 0.05 levels. This shows that there is significant difference of the mean gain scores in Critical thinking skill between experimental and control groups. Hence the null hypothesis was rejected. Since the mean gain score of experimental group (3.4681) is greater than that of control group (1.8718), it can be interpreted that the experiment is effective in Critical thinking skill.

Testing the equality of the pre-test and post-test scores of Critical thinking skill of Experimental and Control Groups

For testing the significant difference of the pre-test and post-test scores on Critical thinking skill test of both experimental and control group , paired t-test was carried out. The obtained result was given in the table (5)

Hypothesis 4: There is no significant difference between the mean pre-test and post-test scores in critical thinking skill between experimental group and control group for the selected sample.

Table5. *Mean post test score, SD, std. error of mean, t-value of experimental and control group between pre test and post test of critical thinking skill.*

	Scores	N	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-tailed)	Remarks
Experimental	Pre critical thinking skill score	47	18.0426	3.70051	.53978	-9.574	0.000	P<0.05 Significant
	Post critical thinking skill score	47	21.5106	4.32321	.63060			

	Scores	N	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-tailed)	Remarks
Control	Pre critical thinking skill score	39	18.5897	3.56679	.57114	-5.655	0.000	P<0.05 Significant
	Post critical thinking skill score	39	20.4615	3.44770	.55207			

From the table (5) it is clear that, the critical ratio obtained for the difference of means of pre-test and post-test scores in critical thinking skill test for the control group is 5.655. It is greater than the value of significance at 0.05 levels. Hence the difference between the mean pre-test scores and post-test scores is statistically significant at 0.05 levels.

From the table it is also clear that, the critical ratio obtained for the difference of means of pre-test and post-test scores in critical thinking skill test of the experimental group is 9.574. It is greater than the value of significance (1.96) at 0.05 levels. Hence the difference between the mean pre-test scores and post-test scores is statistically significant at 0.05 levels. Here both the groups are statistically significant in the mean critical thinking skill test.

Analysis of the effectiveness of STEM Approach on Critical thinking skill test using ANCOVA

In order to confirm the effectiveness of STEM approach Critical thinking skill test, investigator used the statistical techniques of Analysis of Co variance (ANCOVA). Since the Experimental and control groups selected for the study were quasi experimental design, it cannot be concluded that students of two groups (experimental and control), differed significantly by simply comparing the post test scores and gain scores. Hence it is mandatory to test the data by using the ANCOVA, by which the initial differences of two groups (pre test score of Critical thinking skill test) removed statistically, and the initial status can be equated (taken as co-variate).

Hypothesis 5: The post test scores of critical thinking Skill of the experimental group as a result of learning through 'STEM Approach' will be significantly higher than that of post test scores of control group taught through traditional approach of teaching science

The Critical thinking skill of the experimental group who will be taught through 'STEM approach' will be significantly higher than that of the control group taught through traditional approach of teaching science

Statistical technique of ANCOVA was used to test the hypothesis. Table (6) provides the descriptive statistics of the pre-test and post-test scores of both experimental and control groups.

Table6. *Descriptive statistics of the post critical thinking skill score*

Descriptive Statistics			
Dependent Variable: Post critical thinking skills score			
Group	**Mean**	**Std. Deviation**	**N**
Experiment	21.5106	4.32321	47
Control	20.4615	3.44770	39
Total	21.0349	3.96291	86

The mean score of the post test in the experimental group was 21.5106and that of the control group was 20.4615. The standard deviation of the post-test in the experimental group and control group were 4.32321and 3.44770 respectively. Based on the overall descriptive statistical analysis of the post-test scores, it can be concluded that the post test scores of the experimental group were higher than the post-test scores of control group.

Levene's test of equality of error variances

Dependent Variable: Post critical thinking skill score			
F	df1	df2	Sig.
2.425	1	84	.123

Table7. *Tests of Between-Subjects Effects*

Dependent Variable: Post critical thinking skill score					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	902.642[a]	2	451.321	86.661	.000
Intercept	70.854	1	70.854	13.605	.000
Pre critical	879.184	1	879.184	168.818	.000
group	49.957	1	49.957	9.593	.003
Error	432.253	83	5.208		
Total	39387.000	86			

From the table (7) it is clear that the p-value for the group was 0.003 which is less than 0.05. and hence the hypothesis, which states that the post test scores of experimental group on critical thinking skill test will be significantly higher than that of post test scores of control group is not rejected (accepted). Thus the experimental group which is exposed to STEM approach of teaching in science was found to be significantly successful.

The results of the present study were in accordance with the study conducted by the following researchers.

Parno, Edi Supriana, Lia Yuliati, Anula Ning Widarti, Marlina Ali, Umi Azizah (2019) on "The Influence of STEM-Based 7E Learning Cycle on Students Critical and Creative Thinking Skills in Physics". This study showed that the use of STEM-7E learning cycle shows significance differences in increasing student critical thinking skill. There was a significance differences between STEM-7E learning cycle and 7E learning cycle in increasing students' creative thinking.

Tungsombatsanti1, K. Ponkham, and T.Somtoa (2017), The Results of STEM Education Methods in Physics at the 11th Grade Level: Light and Visual Equipment Lesson. assessed students' critical thinking abilities and their satisfaction for enhancing their learning achievements through the instructional approaching management with the STEM education instructional method of secondary students at the 11th grade level. Research indicates that the integration of science with the STEM education method has produced positive effects on student learning.

P. Soros, K. Ponkham, and S. Ekkapim (2018),The results of STEM education methods for enhancing critical thinking and problem solving skill in physics the 10th grade level. The student with learning using STEM Education plan have score of critical think and problem solving skills on post-test higher than pre-test with statistically significant level .01. 2) The student with learning using STEM Education plan have achievement score on post-test higher than pre-test with statistically significant level of .01.

12. EDUCATIONAL IMPLICATIONS

The following are the educational implications of the present study based on the major findings of the study:

STEM approach based teaching of science is found to be more effective in developing Critical thinking skills among students when compared to traditional single subject teaching of science.

As there is a provision for integrating the scientific content to Engineering and technological applications, students were seems to be more active and shows interest to learn the particular content than expected usually.

It is essential to develop critical thinking and problem solving ability among school students. Our society was expecting the same from the educational sector. Hence it is the primary duty of the educationalists and teachers to adopt various innovative teaching strategies and methods in their teaching learning process

National education Policy 2020 recommends giving suitable training to the teachers to use digital technologies for effective teaching learning process.

Science textbooks should be modified based on the requirement of STEM approach of teaching. It could be better if they include various day to day life applications of the scientific content, designing of various applications (videos links), interactive simulations, QR codes for identifying the extra reading materials and information.

13. CONCLUSION

STEM approach based teaching of science is found to be more effective in developing Critical thinking skills. This approach helps the teachers to make the students to think divergently and creatively. STEM approach of teaching science will benefit the students as well as the society to identify the importance of interdisciplinary kinds of learning at secondary level.

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AUTHOR'S BIOGRAPHY

Noufal P, is qualified Master of Science in Physics and Master of Education (M.Ed). His areas of interest are Science Education and STEM Education. He is having more than five years of teaching experience at teacher education level. His teaching specialization is Pedagogy of Physical Science. Currently pursuing Ph.D. in Education from the University of Mysore, Karnataka, India.

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