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Enhancing the Performance of Students in Mathematics: Emphasis on Marzano's New Taxonomy

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Abstract: *This experimental study investigated the effect of an intervention based on Marzano's New Taxonomy of Learning Objectives on academic achievement in mathematics among seventh-grade students by employing the Solomon Four-Group Design. A public sector girls' school in the Haripur district of Khyber Pakhtunkhwa province, Pakistan, was purposively selected, including 247 seventh-grade students. Four groups were randomly chosen, totaling 200 students for the study sample. The intervention incorporated the self-system and metacognitive systems of thinking outlined in Marzano's New Taxonomy of Learning Objectives. The research instrument comprised sixty multiple-choice questions from the Grade VII mathematics textbook. A t-test was employed to compare pre-test scores and to analyze both dependent and independent samples from the pre-and post-tests. The intervention significantly improved the academic achievement of seventh-grade students in mathematics in three months. The findings of this study imply that integrating Marzano's New Taxonomy into mathematics instruction can serve as an effective pedagogical strategy to enhance students' academic achievement and promote deeper cognitive engagement in learning.*

Key Words: Mathematics, Marzano's New Taxonomy of Learning, Quasi-Experimental Study, Student Performance

Introduction

Since the advent of formal education, mathematics has been an essential discipline to learn (Sidhu, 2016). Ehmke et al. (2020) view mathematical ability as necessary for sustainable learning and a productive contribution to society. Pandor (2006) declares mathematics a bedrock for higher education and thus considers it a core subject at the secondary school level. Adequate and high-quality training in this field is essential (Vanderwalt & Maree, 2007). None of the literate societies in the world can ignore the immense potential of this subject for not only the intellectual growth of individuals but also for providing a compatible workforce (National Mathematics Advisory Panel, 2008). All the national documents about education worldwide declare mathematics a compulsory subject from grades one to ten (Common Core State Standards, 2010; National Education Policy, 2017).

A report by the National Mathematics Advisory Panel (2008) says that mathematics is an inevitable element of our societies and is rooted in almost every aspect of our lives (Little, 2009).

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The primary purpose of teaching math is to help students build their thinking ability, not to provide or feed knowledge. Vander-Walt and Maree (2007) suggested that it is up to the teacher to plan metacognitive skills compatible with the subject and encourage students to practice them; however, this effort often proves futile due to educators' inability to prepare adequately. Rocard et al. (2007) concluded that students' inability and low level of concern in science and math stem from teachers' poor choice of teaching methodologies. Due to inconsistent integration within the curriculum, teachers find it challenging to implement these strategies effectively (Trance, 2013).

The ICME-13 (2016) found multiple studies on the significance of problem-solving in math education. These findings give direction to the researchers to innovate and study the concepts and strategies thoroughly, including IBME (Inquiry-Based Math Education), Mathematical Modelling, IMPROVE (Introducing, Metacognitive questioning, Practicing, Reviewing, Verifying, and Enriching) Model for Math Teaching, RME (Realistic Math Education), De Bono's Six-Hat Thinking model, CUN (Complex, Unfamiliar and Non-Routine Task for Teaching Mathematics), etc.

Reading and writing mathematics are the concepts that laid the foundations of mathematical literacy, promoting the new idea of teaching mathematics and paving the way to clarify the subject matter knowledge and methodology to solve a problem (PISA, 2018). The traditional method eliminates reflective thinking and active participation due to the lack of opportunities for students to write mathematical thoughts and discuss ideas (Belbase, 2012; Oguntoyinbo, 2012). Instead of focusing on students justifying a solution by clearly communicating their thoughts (Ministry of Education Singapore, 2010), the focus is on the traditional method of finding the answer via a standard solution process. Interventions increase students' ability to justify a solution (Chua, 2016).

An individual with mathematical knowledge can utilize math across different situations, using mathematical thinking to describe, clarify, and foresee phenomena, thus enabling good societal decision-making (PISA, 2018). Tzohar-Rozen and Kramarski (2014) explored the role of sublevels of metacognition as described by Marzano and Kendall (2007), which include motivation and emotion, in developing self-regulated learners in mathematics. Metacognition is recognized as a strong cognitive tool enabling learners to analyze and understand their situation (Nielsen et al., 2008)When a question requires deep thinking, it engages the individual in self-monitoring while accessing information. Thus, such a question becomes an effective tool for the metacognitive process.

Since the beginning of the 21st century, concerns have been raised about the unsatisfactory outcomes of schooling, prompting efforts to implement teaching strategies that enhance students' interest in learning (Karabenick & Urdan, 2014; Kiemer et al., 2015; Schuitema et al., 2014). Metacognitive components like self-esteem, self-monitoring, and enjoyment have positively influenced math achievement (Brandenberger et al., 2018). However, promising learner traits such as motivation, confidence, and critical thinking decline during the transition from primary to secondary education (Gnambs & Hanfstingl, 2016). Interventions incorporating goal-setting (Morisano et al., 2010) and affective engagement (Peker, 2016) show potential for reversing this trend. The Swiss government's education reforms emphasize the importance of sustaining learner motivation (The Swiss National Science Foundation, 2018). Yet, despite teacher efforts, widespread student dissatisfaction persists, with 73% expressing disinterest in mathematics due to insufficient conceptual teaching (Agarwal, 2009). Alarmingly, only 2% of U.S. Grade 12 students attained excellence in mathematics (*U.S. Department of Education, Institute of Education Sciences*, NCES, 2005), and scores have declined globally, as seen in Romania and Wales (Badescu & Stan, 2020; Hopkins, 2016). Researchers advocate for diverse strategies that engage students in higher-order thinking tasks (Dillon, 2002; Facione, 1990). While teaching math, educators can use textbooks (Johansson, 2006), often neglecting techniques that enhance metacognitive abilities, which are superior to cognitive methods (Marzano & Kendall, 2001). Marzano and Kendall (2007) introduced the concept of monitoring interest, which can help address learner disengagement at the beginning of thinking processes.

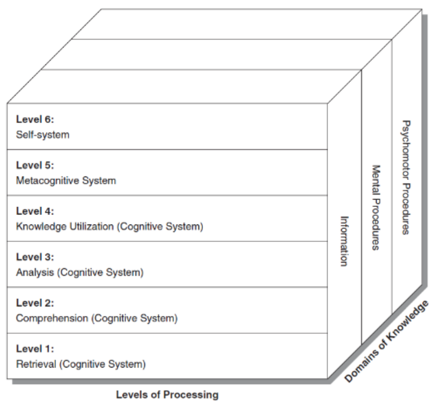
Anzalone (2010) found that learners often exhibit overconfidence in their mathematical ability, cautioning educators to apply strategies to boost self-efficacy carefully. Learners' self-predicted performance frequently exceeded actual results, highlighting the need for metacognitive regulation of self-awareness (Schunk & Ertmer, 2000; Sperling et al., 2004). Wagner (1982) criticized the lack of awareness regarding metacognitive processes in schools, a concern echoed decades later by Kristianti et al. (2017), who noted that content-driven mathematics teaching fails to engage students meaningfully. Brandenberger et al. (2018) reported that mathematics is often perceived as difficult, evoking negative emotions. Gender disparities are also notable, with girls generally showing less motivation and confidence in mathematics than boys (PISA, 2010) and making different career choices due to the perceived relevance of mathematics.

This taxonomy shares a two-dimensional layout, namely knowledge and procedure, with (Nielsen et al., 2008); however, it attempts to address the shortcomings identified in that work. A significant departure from Marzano's New Taxonomy (MNT) is separating different knowledge levels from the cognitive procedures that operate on specific knowledge types (Marzano & Kendall, 2007). Another distinctive feature of this taxonomy is recognizing the pivotal role of metacognition and the self-system in the learning process. The self-system serves as the initial cognitive response to a new task. It concurrently begins to evaluate the task's importance, motivation potential, and the learner's efficacy level (Irvine, 2017).

Engagement with a new learning task depends on the learner's decision, which is primarily influenced by the self-system, accompanied by metacognition, along with cognitive processing. The self-system integrates an individual's dispositions, philosophies, and feelings. The close interaction of these elements generates motivation and devotion (Marzano & Kendall, 2007). Another distinguishing feature of the new taxonomy is the element of metacognition, which will be discussed in detail alongside the self-system. The primary focus of this study, critical thinking, exists within these two domains. The cognitive domain encompasses four sublevels: knowledge utilization, analysis, comprehension, and retrieval, which correspond to the sublevels of synthesis, analysis, comprehension, and recall in Bloom's taxonomy.

Figure 1

Two-Dimensional Taxonomy of Learning (Marzano & Kendall, 2007)



In contrast to oversimplifying the nature of human thought as presented in Bloom's Taxonomy, Marzano acknowledges human cognition's multifaceted and complex nature. The self-system encompasses the underlying energies of human cognitive activity, including inclinations of the mind, personal philosophies, and emotions. Together, these elements generate the driving force for new learning tasks and the commitment to accomplish them (Marzano & Kendall, 2007). Irvine (2017) refers to this as a bottom-up approach in contrast to the taxonomy offered by Bloom, as the former considers the self-system to be essential in determining if the learner will get engaged with learning tasks. The four aspects of thinking generated by the self-system are: "examining importance, examining efficacy, examining emotional response, and examining overall motivation.

1. Examining the importance:
2. Learning tasks gain importance if they satisfy basic human needs (Maslow's hierarchy) or align with personal goals, as confirmed by psychological research (Marzano & Kendall, 2007).
3. Examining the efficacy:
4. A learner's belief in their ability to succeed directly impacts motivation; self-doubt weakens engagement (Marzano & Kendall, 2007).
5. Examining Emotional Response:
6. Emotions strongly influence motivation and behavior, sometimes outweighing beliefs; learners assess emotional value upon encountering a task (LeDoux, 1996; Marzano's Taxonomy).

The metacognition system observes, appraises, and adjusts all cognitive activities (Brown, 1986; Flavell, 1976). These attributes give this system exclusive control of mental functioning. As specified by Marzano and Kendall (2007), the following are the four functions of this system:

1. Specifying Goals: The metacognitive system determines relevant learning goals once the self-system decides to engage in the new task.
2. Process Monitoring: Whether the mental or physical procedure that the learner is using works effectively. In the presence of a specific goal, it is observed if the procedure leads to achieving that goal.
3. Checking for being Clear
4. Checking for being Accurate

The last two functions are considered dispositional (Brown, 1986; Flavell, 1976). If the learner desires to be conscious of the clarity and accuracy of the acquired knowledge, only then can they monitor these elements.

Research Hypotheses

The Following Null Hypotheses were Formulated

1. There is no significant difference in mathematics achievement of the experimental group (with pre-test) and the control group (with pre-test) in the pre-test of mathematics".
2. There is no significant difference in pre-test and post-test scores of mathematics achievement of the experimental group (with pre-test).
3. There is no significant difference in pre-test and post-test scores of the mathematics achievement of the control group (with pre-test).
4. There is no significant difference in post-test scores of the mathematics achievement test of the experimental group (with pre-test) and the control group (with pre-test).

Research Methodology

The present study is an experimental research project utilizing a quasi-experimental Solomon Four Group design. All experimental studies adhere to the principles of scientific research. In education, scientific research employs organized methods to enhance understanding and improve the teaching and learning process (Lodico et al., 2010). Towne et al. (2005)

emphasize the significance of scientific research in providing logical and accurate knowledge to policymakers and practitioners in the field of education.

Intervention

Luka (2014) believes that outdated teaching methods have become less effective in meeting the emerging needs of educational outcomes. Literature provides empirical evidence of using pedagogical interventions and their positive outcome in education (Albay, 2019; Retna, 2016; Al-Rahili, 2007; Al-Hisan, 2008; Ahmad, 2008; Houston, 2017). The present study involves an intervention based on Marzano's New Taxonomy of Learning as a pedagogical framework. Thirteen lesson plans were developed covering five content strands of the seventh-class mathematics textbook, comprising of

- Math of Financial Calculation
- Learning Algebra, Linear Equations,
- Basics of Geometry
- Applying concepts of Geometry
- Data Handling.

Marzano and Kendall (2007) consider their offered taxonomy as easier for practitioners to use when designing classroom instruction. The two-dimensional structure of this taxonomy, discussed thoroughly earlier, allows teachers to distinguish between the cognitive process and knowledge type involved in a specific educational objective. Self-system comes into play as soon as new learning is offered. The lesson plan opens to address the self-system activity of evaluating the importance of a new task, then guessing the chances of success, and if these chances of success could be made evident, it will generate positive feelings in the learner.

Population and Sample of the Study

This study's population consisted of all students in the Seventh Grade (227) at a public sector school in the Haripur district of Khyber Pakhtunkhwa province of Pakistan.

Sadgwic (2015) defines multistage sampling as involving random selection in two or more phases, beginning with naturally occurring population units and then randomly selecting subjects within those units. This study chose the institution as a typical urban public school (typical case sampling) for its representativeness and adequate student population. Subsequently, intact classroom groups were randomly designated as experimental or control, rather than randomizing individual students (200 students). A similar approach was employed by McGahee and Tingen (2009) in a study on smoking prevention, where four schools were conveniently sampled and randomly assigned to SFG groups. This method, known as cluster randomized sampling (Lopata et al., 2018; Spybrook, 2020), was applied with 180 female students from four sections, randomly designated as control or experimental. According to Hourichi et al. (2018), such cluster randomization reduces the risk of treatment contamination.

The status and number of students in each study group are presented in the table below.

Table 1

Details of Four Study Groups

Section	Group Description	No. of Students	Pretest Code	Group Description	No. of Students	Posttest Code
A	Control with pretest (CWPT)	43	1	Control with pretest, and Posttest Scores	42	3

Section	Group Description	No. of Students	Pretest Code	Group Description	No. of Students	Posttest Code
				CWPOT		
B	Experimental without pretest (EWOPT)	44	-	Experimental without pretest, Posttest Scores EWOPRPOT	42	4
C	Experimental with pretest, and pre-test scores (EWPT)	45	2	Experimental with pretest, post-test scores EWPRPOT	45	5
D	Control without pretest (CWOPT)	48	-	Control without pretest, Posttest Scores CWOPRPOT	40	6
E	Eliminated During Random Assignment	46	-	-	-	-

Although Mahishwari et. al., (2017) referred to random assignment as the most critical element of experimentation. In the absence of a random assignment of the individuals, every possible effort was made to equate study groups in terms of age, gender, achievement, and socioeconomic status, because if the subjects of the study are different from each other before the outset of the experiment, we cannot be sure that the intervention causes behavior change. Any differences found in subjects ought to be controlled as much as possible.

Math Achievement Test (MAT) Using MCQs

To use a test prepared by the researcher is considered more appropriate for the context of the study as compared to standardized test (Lodico et al., 2010). For example, the population's efficiency in reading possibly be different from what is expected or could be lower. Similarly, the assumption regarding the population's prior knowledge may not hold for the population in this study. Therefore, the researcher decided to develop the tool independently.

MAT initially consisted of 80 items from seven units (7-13) of the Grade VI and VII Mathematics Textbook. The revised version of the test produced after the pilot study comprised 60 items (21 from VI and 39 from VII:35%,65%). The five content strands and the number of items taken from each are as follows:

- Math of Financial Calculation 09
- Learning Algebra, 10
- Linear Equation 07
- Basics of Geometry 17
- Applying concepts of Geometry 05
- Circumference Area, and Volume 09
- Information Handling 03

Validity of the Tool

The tool was validated, and its reliability was checked through multiple methods, such as expert opinions and field testing. A detailed understanding of tool development, validation, and reliability checking was done by the researcher Bano et al. (2021) in developing a valid and reliable mathematics achievement test published in Ilkogretim Online - Elementary Education Online.

Data Analysis

The statistical tests used for analyzing data obtained in this study included the T-Test to find if there is a significant difference between the means of two different samples and the paired t-test to compare the pre-and post-test scores of the same group. Cohen's d was used to determine the effect size of the differences found in the means of two independent or dependent groups. At the same time, descriptive analysis was applied to the data obtained from the socio-economic survey. Assumptions for the t-test include data measured on a continuous scale, a large sample size (N>30), and a normal sample score distribution. Scores for the mathematics achievement tests and critical thinking tests were measured on a continuous scale.

Table 2

Comparison of pre-test mathematics achievement scores of Control and Experimental groups (with pre-test)

Group	N	M	SD Score	SE Mean	t-value	Sig.	Effect Size
CWPT	48	20.94	2.81	0.40	.174	.862	0.03W
EWPT	50	20.82	3.77	0.53			

*p>0.05

Table 1 presents the analysis of the independent sample t-test of a control group with pretest, and pre-test scores (CWPT) and an experimental group with pretest, and pre-test scores (EWPT) of the mathematics achievement test. T-test values for CWPT (Mean= 20.94, SD= 2.81, SE Mean= 0.04) are greater than pre-test EWPT (Mean= 20.82, SD= 3.77, SE Mean= 0.53). T-value (0.178) is used to examine the difference. The p-value (0.862) with a weak effect size (0.03) is higher than 0.05; thus, statistically, the difference between the two groups is insignificant. The performance of CWPT and EWPT in mathematics achievement in the pre-test is the same, and the researcher accepted the H_{01} null hypothesis.

Table 3

Comparison of pre-test and post-test scores of the mathematics achievement test of Experimental Group (with pre-test)

Group	N	Mean	SD Score	SE Mean	t-value	Sig.	Effect Size
EWPT	50	20.82	3.77	0.53	-5.146	.000	1.13
EWPRPOT	45	27.35	7.73	1.15			

*p<0.05

Table 2 shows the comparison of the pre-test and post-test of the same group, that is experimental group with the pre-test. T-test values for EWPT (Mean= 20.82, SD= 3.77, SE Mean= 0.53) are less than EWPRPOT (Mean= 27.35, SD= 7.73, SE Mean= 1.15). The t-value for the comparison of both groups (-5.146) renders the difference between the two groups significant (0.000) with a strong effect size (1.13) at a confidence interval of 0.05. The experimental group with the pre-test (EWPT) outperformed in the post-test. Thus, the researcher rejected the H_{02} null hypothesis.

Table 4

Comparison of pre-test and post-test scores of mathematics achievement test of Control Group (with pre-test)

Group	N	Mean	SD Score	SE Mean	t-value	Sig.	Effect Size
CWPT	48	20.94	2.81	48	-.827	0.411	0.17
CWPOT	42	21.55	4.00	42			

*p>0.05

Table 3 represents the comparison of the pre-test and post-test of the same group, that is control group with the pre-test. The values for CWPT (N= 48, Mean= 20.94, SD= 2.81, SE Mean= 48) are less than CWPOT (Mean= 21.55, SD= 4.00, SE Mean= 42). T-value (-0.827) reveals the difference between the pre- and post-test is insignificant (p=0.411) with a weak effect size (0.17) at a confidence level of 0.05. The scores of CWPT remained the same in the post-test. Thus, the researcher accepted the H_{03} null hypothesis.

Table 5

Comparison of post-test scores in mathematics achievement test, of the Control Group and Experimental Group (both with pre-test)

Group	N	Mean	SD Score	SE Mean	t-value	Sig.	Effect Size
CWPOT	42	21.55	4.00	0.62	-4.442	*.000	1.00
EWPRPOT	45	27.36	7.73	1.15			

*p<0.05

Table 4 presents the comparison of post-test scores of the control group with pre-test, and the experimental group with pre-test (EWPRPOT) for the mathematics achievement test. t-test values for CWPOT (Mean= 21.55, SD= 4.00, SE Mean= 0.62) are less than values for EWPRPOT (Mean= 27.36, SD= 7.73, SE Mean= 1.15). T-value (-4.442) indicates that the difference between the two groups is statistically significant (p=0.000) with a strong effect size (1.00), at a confidence level of 0.05. The EWPRPOT outperformed the CWPOT in the mathematics achievement test post-test. Thus, the researcher rejected the H_{04} null hypothesis.

Discussion

This study found that Marzano's New Taxonomy of Educational Objectives significantly enhances students' achievement in mathematics. Initially, both experimental and control groups demonstrated statistically equivalent performance on pre-tests (H01), confirming group comparability before the intervention. However, following the implementation of taxonomy-based instruction, students in the experimental group exhibited notable gains in achievement (H02), clearly highlighting the framework's effectiveness in promoting deeper understanding and academic success in mathematics.

The consistent performance across experimental groups, irrespective of pre-test exposure, and the significant post-test differences (H04) further reinforce the conclusion that the observed improvements can be attributed to the intervention itself, rather than testing effects or extraneous variables. These outcomes indicate a cause-and-effect connection between the use of Marzano’s taxonomy and the enhancement of mathematical achievement (H02), emphasizing its stable and positive influence across varied learning contexts.

The significant improvement in mathematics achievement aligns with existing literature supporting the effectiveness of inquiry-based and problem-based pedagogical approaches. Marzano's taxonomy, as an intervention, yielded improved scores in the experimental groups, consistent with findings from Chin and Lin (2013), Engeln et al. (2013), Singer et al. (2015), and Albay (2019), who all advocate for active, cognitively engaging instructional models. Perry et al. (2012) further reinforced this notion through a meta-analysis revealing the national-level impact of metacognition-based strategies on learning outcomes.

Similarly, Alrababah (2017) found that integrating Marzano's Dimensions of Learning into science instruction enhanced students' critical thinking. Al-Rahili (2007) and Ahmad (2008) confirmed that Marzano's strategies cultivate deeper conceptual understanding and positive learning dispositions. Mevarech and Kramarski's (1997) metacognitive intervention also led to significant gains in mathematical achievement, improved self-regulation, and reduced math anxiety among younger learners. Additional support comes from Toheed (2017), whose quasi-experimental research on mastery learning strategies showed favorable results for the experimental group, and Rehman (2011), who demonstrated that brain-based learning strategies grounded in cognitive readiness and emotional engagement improve mathematical learning.

These findings highlight the transformative potential of structured, cognitively engaging pedagogies such as Marzano's taxonomy. When thoughtfully applied, such frameworks improve academic performance and foster essential cognitive skills, paving the way for sustained achievement and conceptual mastery in mathematics education.

Conclusions & Recommendations

This study concludes that the New Taxonomy of Educational Objectives offered by Marzano is a highly effective instructional framework for enhancing students' achievement in mathematics. The significant gains observed among students in the experimental group, compared to their control group counterparts, demonstrate that taxonomy-based instruction fosters more profound understanding and academic growth. The initial equivalence of groups and the consistent post-intervention performance, regardless of pre-test exposure, confirm that the improvements were due to the instructional intervention, establishing a clear causal link between using Marzano's taxonomy and improved learning outcomes.

These findings are statistically significant and supported by a growing body of literature advocating for cognitively engaging, metacognitive, and inquiry-driven approaches to teaching. By aligning with prior research and demonstrating practical effectiveness, this study reinforces the value of Marzano's taxonomy in transforming traditional mathematics instruction. It supports the notion that when pedagogical strategies prioritize critical thinking, cognitive engagement, and structured learning processes, they can meaningfully enhance student achievement.

Moreover, this research underscores the need for educators to integrate evidence-based frameworks like Marzano's taxonomy into classroom practices. Doing so can lead to more effective mathematics teaching and improved academic performance. The present study has used an experiment with a female student only. A study taking both genders in the sample may be conducted to see if gender-based variation exists in the study outcomes. The same study may be replicated with rural school students to see if it produces the same results for students with rural backgrounds. A longitudinal study may be designed using the lesson plan approach, incorporating the New Taxonomy of Learning offered by Marzano, for grades six, seven, and eight, to see if it produces sustainable improvement in critical thinking and mathematics achievement scores.

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