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Relationship between Logical Thinking, Metacognitive Skills, and Problem Solving Abilities: Mediating and Moderating Effect Analysis

Abstract: This study analysis is aimed at examining the relationship between logical thinking, metacognitive skills, and problem-solving abilities. To accomplish the research purpose, 100 senior secondary school students were surveyed. A descriptive survey method was adopted to examine the study results. Logical thinking, problem-solving abilities, and metacognitive skills scales were used to assess students' skills. These three scales have been pretested and have good reliability and validity. The collected data was analysed using correlation and multiple regression techniques. Pearson product-moment correlation results show a significant relationship between study variables. Further, results of the comparison show that problem-solving abilities differ significantly on the basis of gender and stream of the students. Mediation analysis revealed that logical thinking fully mediates the relationship between metacognition and problem-solving abilities. In the present study, logical thinking accounts for 52.4% of the total effect. Moreover, the result of the interaction of metacognition and logical thinking skills on problem-solving abilities is significant, which leads to the conclusion that logical thinking also works as a moderator between the predictor and outcome variable.

Keywords: *Senior secondary school students, Logical thinking skills, Problem-solving abilities, Metacognitive skills, Mediator, Moderator*

INTRODUCTION

Knowledge is the key to success for every student. Along with knowledge, they must learn various skills such as logical thinking, problem-solving ability, and metacognitive skills to become more creative and innovative in their respective fields of study. Students need to follow the latest changes in educational curriculum development, integrate technology during the learning process, and internalise positive character. They also have to cope with different problems on the path to success. As a result, they must acquire new skills to become more creative and innovative in their respective fields, which will assist them in improving their performance and achieving their desired goals. Logical thinking, problem-solving ability, and metacognitive skills are interrelated. Students are given special classes to increase these skills and become more competitive.

Logical Thinking

Logical thinking is the process of thinking actively with the help of different concepts and judgments. It is the cognitive process in which objectives are reflected actively in the mind with clear concepts and judgment. It is an art that helps analyse a situation and find a solution. Logical thinking needs reasoning skills that help in the study of the problem and help find the solution using the available facts and information about that situation. It is a mental process in which a person uses his thought process to find a problem (Piaget, 1969) and helps in solving the problem using the power of reasoning from the gathered information and facts. It is a rational process in which the human mind scientifically finds the solution to a problem, but this skill is not easy to master (Haygood & Bourne, 1965). Generally, people organise information into general and specific classes (Matlin, 2009) and conclude mathematical reason and logic (Anthony, 2008). A person can solve any

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problem through logical analysis and thinking (Widodo & Turmudi, 2017). Thinking logically is very important in students' day-to-day life. It requires reasoning skills and diverse thinking abilities to look at a situation objectively and arrive at a solution based on the facts. It also aids in better decision-making, and the greater a person's thinking ability, the easier it is to comprehend problems and find appropriate solutions (Juhanda, Rustaman, & Wulan, 2019). Logical thinking skills use reasoning in such a manner that allows an individual to solve a particular problem. This skill also allows students to analyse problematic situations, helping them make important decisions, identify the problem, generate creativity, and set goals. While analysing a situation, students collect data and use this gathered information to solve the problem. All these things play an important role in developing the student's career.

Most importantly, logical thinking is not a genetic quality; it can be learned (Albrecht,1984) with the technological pedagogical content knowledge learning model **(**Muzaky & Sunarno, 2020). It is an essential factor in solving any problem (Howe & Jones, 1993). Even in schools and colleges, different activities are conducted that help students increase their thinking power and reasoning ability to solve problems in the best possible way. In this manner, logical thinking is an important skill for students (Holyoak & Morrison, 2005), enabling them to focus on a particular task and find relationships between data and information.

Problem-solving ability

Every person has problems in this world, and students are no exception. As a result, problem-solving abilities are essential for everyone, including students in the twenty-first century (Annetta, 2008). Problem-solving is a goal-directed, creative activity in which the goal is to remove obstacles and find an effective solution to that problem. According to Skinner (1968), "Problem-solving *is the process of overcoming difficulties that appears to interfere in the attainment of a goal" (cited in Mangal, 1990, p. 271).* These are the strategies used to solve problems scientifically in any area. It is a mental process that helps us increase our logical thinking power (Piaget, 1969) and aids in developing skills required to solve problems that students will face in the classroom or society (Zahroh et al., 2018). Hence, the ability to identify underlying causes, find solutions, and avoid problems is called a problem-solving ability (Chan & Wu, 2007). It is considered the most complex level of cognitive activity that occurs simultaneously. It is triggered by the person's intellect, including memory, perception, reasoning, conceptualisation, language, emotion, motivation, self-confidence, and the ability to control the situation (Caprioara, 2015).

Problem-solving ability includes logical thinking (Robbins, 2011), so problem-solving and logical thinking are interrelated concepts. The rational brain process solves problems but is tough to master (Haygood & Bourne, 1965). Both flexibility and effectiveness should be considered when evaluating problem-solving abilities. While flexibility allows for a wide range of unique solutions to a problem, effectiveness ensures that the solutions are practical and well-thought-out. Students who learn problem-solving tricks and increase their logical thinking skills become more successful in their life. Students with higher problem-solving abilities feel less stress and depression (D'Zurilla, Chang, Nottingham IV, &Faccini, 1998) and easily find solutions to their problems. Lack of problem-solving abilities leads to hopelessness and depression, which raises the risk of suicide (Dixon, Heppner, & Anderson,1991). Hence, students must be taught and trained in problem-solving strategies. It can assist them in identifying and solving problems, emphasising the interconnected nature of problems and problem-solving practice in a non-threatening environment (Kapp, 2007).

Metacognitive skills

Flavell coined the term "metacognition" and defined it as the understanding of metacognitive processes such as assessment, supervision, and regulation (Flavell, 1979). Flavell (2000) described meta-cognitive skills in two ways: knowledge and processes. These skills help one understand how one solves problems in different situations and generally find the solution to the problem. Metacognition has recently been broadened to include not only 'thoughts about thoughts', but "knowledge of one's knowledge, processes, cognitive and affective states, as well as the ability to consciously and deliberately monitor and regulate one's knowledge, processes, cognitive and affective states" also (Papleontiou-Louca, 2003, p.10-11). Martinez (2006) described metacognition as "the monitoring and controlling of thoughts". Lai (2011) argued that metacognition is a multidimensional set of skills that involves "thinking about thinking". Meta-cognitive skills refer to a person's ability to comprehend, control, and manipulate cognitive processes; these skills can be taught to improve learning (Safari & Meskini, 2016). These skills are executive skills that monitor and regulate one's cognitive activities and include logical thinking and problem-solving abilities. Meta-cognitive skills allow students to learn about their beliefs, attitudes, and experiences and help relate these internal states to the external environment. These skills help summarise the given information and understand the meaning of summary or abstract. Further, these skills help increase students' thinking power (Hatano & Inagaki, 1986).

Various activities are conducted at the school level to increase students' meta-cognitive skills. With the help of these skills, students can choose the best possible way to achieve their goals. John Flavell, the "Father of the Field" initiated research on metacognitive development in the 1970s and asserted that metacognitive skills are important abilities that facilitate students' overall growth and development. Metacognitive skills are also listed as one of the main competencies for individuals in the twenty-first century by the European Union. Many examples of metacognitive skills include planning, thinking, judgment,

meditation, and regulation. These skills help young learners plan, monitor, and evaluate and solve problems quickly (Diaz, 2015). These skills help develop the planning process in the students' minds, which helps improve their logical skills and aids in their progress in different areas. With the help of these skills, problem solvers become aware of their strengths and weaknesses in a particular area. These skills help in building confidence among students, which helps in self-assessment. Students face many problems while solving problems in their daily lives related to exams, competitions and getting knowledge about many more things to remain competitive. In this era, one must understand the importance of logical thinking and metacognitive skills to survive in a world full of competition. It helps increase creative and logical power among students, which helps them quickly solve their problems. Moreover, metacognitive activities in schools help motivate students to increase their concentration and help them understand the concepts deeply (Karaali, 2015).

Meta-cognitive skills help in increasing the problem-solving ability of students. This further helps in learning mathematics easily (Arani & Mobarakeh, 2012). Problem-solving ability is a complex interaction of cognition and metacognition (Kazemi, Yektayar, and Abad (2012). Perhaps the most fundamental source of difficulty in problem-solving is that students cannot actively monitor, check, and regulate the cognitive processes while solving problems (Artzt & Armour-Thomos, 1992). Metacognitive practices help students transfer and adapt their learning to new contexts and tasks (Schoenfeld, 1991). Those who understand their strengths and weaknesses are more likely to actively monitor their learning strategies and resources and assess their readiness for specific tasks and performances (Bransford, Brown, & Cocking, 2000). Schoen (1983) defines meta-cognitive skills as a successful pedagogy. It can be a basis for enhancing logical thinking about making ideas and plans to solve the problem encountered. Metacognitive skills are strategies that are applied in the problem-solving process. Students with good metacognitive skills are more confident and independent learners.

It should be noted that previous studies have indicated that metacognitive skills, logical thinking and problem-solving ability are essential skills. The findings of this study will be valuable to instructors, students, and other stakeholders in the field of education. Furthermore, the literature review revealed that only a few studies had been conducted to understand the interrelationship between these three variables. There is limited evidence in the literature regarding the effects of logical thinking on problem-solving abilities. The present study can help in understanding the relationship between logical thinking, problem-solving ability, and meta-cognitive skills among school students. Mefoh et al. (2017) and D'Zurilla, Maydeu and Kant (1998) reported significant gender differences in problem-solving abilities.

Moreover, gender differences have been reported in metacognitive strategies (Liliana, & Lavinia, 2011; Nunaki, Damopolli, Kandowangko, & Nusantri, 2019 & Wu, 2014) and logical thinking (Bektasli & White, 2012, Zaman, Farooq, Hussain, & Ghaffar, 2017 and Mwamwenda, 2018). Mumford et al. (2010) observed cross-field differences in creative problem-solving abilities. Gender bias can influence results (Holdcroft, 2007), and gender analysis can provide empirical evidence for the research taken as a whole. The studies discussed above suggest that there is a reason to suspect that metacognitive skills, logical thinking and problem-solving ability are linked with gender and stream. The literature suggests relationship analysis cannot address a question like why, how and for whom a relationship holds (Fairchild & McQuillin, 2010). In the literature, bivariate relationships between the variables have been reported. However, no evidence could be traced regarding the moderating and mediating role of logical thinking in the relationship between metacognitive skills and problem-solving ability. Based on the literature, metacognitive skills have been taken as an independent variable and problem-solving ability as a dependent variable. Hierarchical regression and interaction effect give evidence for moderating and mediating effect. Moreover, such questions (how, why and whom) can be answered only by analysing higher effects among variables. Mediating effects are very popular in psychological research because, at later stages, these become the basis for theory development (MacKinnon, Fairchild, & Fritz, 2007) and adding a third variable in the relationship may help understand spurious relationships (MacKinnon, Fairchild, & Fritz, 2007). Therefore, to extend these arguments following research questions have been examined in the study.

Research Questions

The present study investigates the association between metacognitive skills, logical thinking skills, and problem-solving abilities. The following research questions regarding the association between the three variables of interest were raised based on the literature review.

RQ1: Does gender and stream (art, Commerce, and Science) influence students' metacognitive skills, logical thinking skills, and problem-solving abilities?

RQ2: Do metacognitive skills related to logical thinking skills and problem-solving abilities?

RQ3: To what extent do metacognitive and logical thinking skills explain differences in problem-solving abilities?

RQ4: Is logical thinking works as a mediator for the association between metacognitive skill and problem-solving abilities?

RQ5: Is logical thinking works as a moderator for the association between metacognitive skill and problem-solving abilities?

MATERIALS AND METHODS

Participants

The present study is descriptive, and a survey method was used to collect the data related to the variables for the study. A sample of 100 senior secondary school students

(aged 15 to 19 years) from the Sonipat district was examined. For this purpose, five schools from the Sonipat district were selected using random sampling to examine these students' meta-cognitive skills, logical thinking, and problem-solving abilities. The investigators met with the principals or director of the school and explained the purpose of the survey. Then the researcher went to the classroom and built a good rapport with them. Good rapport entails developing a harmonious relationship and mutual trust with the research participants in order to obtain honest responses. First of all, the researchers introduced themselves, followed by discussing the outline of the study to make them comfortable. Participants were assured that their responses would be used for research purposes only and kept confidential. Participants' consent for participating in the study was sought before data collection. The researcher explained the purpose of the survey and gave them the necessary directions to fill out the questionnaire. Participants were provided with all three questionnaires simultaneously, and there was no time limit for filling them. Participants filled all the questionnaires in paper-pencil mode at the same time.

Tools used

Logical thinking scale: Dr. Sujeet Kumar and Ms. Shikha Tiwari developed the logical thinking test in 2012. This scale contains 50 items related to reasoning and logical thinking to assess the power to think logically. These 50 items are divided into five categories such as series/sequence, completing the analogous pair, classification, coding-decoding, and relationship. Each category consists of 10 items. In *series/ sequence* category, candidates are required to find out the patterns of given series (e.g. Question is *2,2,2, 5, 5, 5, 8, 8, 8,?* Options are *(A) 7 (B) 10 (C) 9 (D) 11*). In the case of *completing the analogous pair*, two words are given which are related in some manner (Question is *ABC: ZYX:: CBA:?* Options are *(A) XYZ (B) YZX (C) ZXY (D) XZY).* Students are required to find out the relationship between these words and choose similar words from alternatives. *Classification* means to assort items on the basis of certain common qualities or spot the stranger out. *Coding and decoding* questions are set to judge the candidate's ability to decipher the message *(If CITY is 1234 and ZENITH 567238, then how will we write CITIZEN?* Options are *(A) 1232567 (B) 123368 (C) 123347 (D) 132347)*. In *relationship* type questions a roundabout description is given for certain relationships and the direct relationship between persons is to be deciphered. The reliability of the logical thinking test has been calculated using the K-R formula is 0.83.

Problem-solving ability scale: Mr. L.N. Dubey developed the problem-solving ability test in 2019. Problem-solving is the framework or pattern within which creative thinking and reasoning occur. The scale contains 20 problems related to mathematics and reasoning ability to check the problem-solving ability. The items are like *adding twice to any number in that number and subtracting half of that number comes 50, then what will be that number?* The reliability of the problem-solving test was calculated by the split-half (odd-even) method (.78) and by the Kuder-Richardson Formula (.76) (Rational Equivalence Method).

Meta-cognitive skill scale: Dr. Madhu Gupta and Ms. Suman developed the meta-cognitive skills scale in 2017. This scale consists of 42 items based on four dimensions of meta-cognitive skills, i.e., planning skills, implementing skills, monitoring skills, and evaluation skills. Planning skills include the ability to manage self and others. It includes items like, *'I breakdown big assignments into sub-parts.'* Implementation skill measures learner's willingness to execute required actions. E.g., *'I use planned structure for comprehensive learning'.* Monitoring refers to one's awareness of monitoring own progress (*'I keep track of my progress towards my set goals'*). Evaluation skills measure the ability to access and reflect on the processes employed and the finished product. E.g., *'I evaluate the whole progress whether it corresponds with planning'*. The scale's reliability has been measured by the test-retest method (.763) and the split-half method (.949).

RESULTS

Descriptive statistics

Descriptive statistics for variables is done before conducting the main hierarchical regression analysis to examine the relative contribution of metacognitive skill and logical thinking to problem-solving abilities and the association between the variables. Results from Table1 demonstrate that the level of logical thinking is above-average for most students (M=34.7, SD=6.57) and follows the light-tailed distribution. Most of the students have average meta-cognitive skills (M=163, SD=16.9). The kurtosis was found to be 2.71, indicating that distribution is very close to normal distribution

Table 1 also depicts that most of the students have average levels of problem-solving abilities (M=10.1, SD=3.53). The kurtosis for problem-solving abilites was found to be -0.756, indicating that the distribution is flat and most of the values lie on the left side of the distribution (Sk=-0.388).

Table 1. Descriptives Statistics (n=100)

Variables	Mean	Standard Deviation	Minimum	Maximum	Skewness	Kurtosis
Logical Thinking Skills	34.7	6.57	19	45	-0.486	-0.916
Metacognitive Skills	163	16.9	91	197	-0.936	2.72
Problem Solving Abilities	10.1	3.53	3	17	-0.388	-0.756

RQ1: Exploring the influence of gender and stream (art, Commerce, and Science) on metacognitive skills, logical thinking skills, and problem-solving abilities

In order to compare the variables (metacognitive skills, logical thinking skills, and problem-solving abilities) on the basis of gender, an independent t-test was used. Results of comparison from Table 2 demonstrate that logical thinking skills do not differ significantly based on gender (female (M=34.22, SD=7.00) male (M=35.3, SD=6.07) t=-0.802, p=0.424) among senior secondary school students. Further, it is evident from Table 2 that meta-cognitive skills between females (M=167.09, SD=13.67) and males (M=157.4, SD=18.86, t=2.981, p=0.004 and effect size=0.598) in senior secondary school students differ significantly. Table 2 demonstrates that the problem-solving abilities between males (M=10.4, SD=3.30) and females (M=9.87, SD=3.73), and senior secondary students do not differ significantly (t=-0.764 and p= 0.447). It means male and female students do not differ in logical thinking and problem-solving abilities. However, female students have shown better metacognitive skills than their male counterparts.

One-way ANOVA was conducted to explore the difference between these variables on the basis of the stream (art, Commerce, and Science). The results of the comparison based on streams (i.e., Science, art, and Commerce) have been shown in Table 3. It is clear from the results that logical thinking for Science (M=35.15, SD=6.14), Arts (M=34.59, SD= 6.87), and Commerce (M=32.40, SD=6.87) students do not differ significantly (F=0.413, p=.670). Results from Table 3 depict that the metacognitive skills of Science (M=165, SD=22.24), art (M=161, SD=11.84) and Commerce (M=158, SD=12.99) students do not differ significantly (F=0.543, p=.596).

Table 3 illustrates a streamwise comparison of problem-solving abilities in Science (M=10.05, SD=3.41), art (M=10.56, SD=3.41) and Commerce (M=6.00, SD=2.65) students differ significantly (F=6.06, p<.05). Further, posthoc analysis was conducted using Tukey's test, and it was found that Commerce students differ significantly from both Science and Arts in problem-solving abilities and have been found to possess poor problem-solving abilities.

Two-way ANOVA was performed to analyse the effect of gender and stream on logical thinking skills, metacognition skills and problem-solving abilities. Simple main effect analyses showed (see Table 4, 5 & 6) that gender did not significantly affect logical thinking skills, metacognition skills and problem-solving abilities. The main effect of the stream was found to be significant in the case of problem-solving abilities (F=4.51, p<.05). The results presented in Tables 4 and 5 indicated that there was a statistically significant interaction between the effect of gender and stream on logical thinking skills (F=4.9, p<0.05) and metacognitive skills (F=4 .38, p<0.05). However, in the case of problem-solving abilities, insignificant interaction effect gender and stream was observed (F=1.91, p=.154). Mean Plots were also plotted to visualise the interaction effect better for all the three dependent variables under study.

Figure 1 shows that female Science students have better logical thinking than their male counterparts. In contrast, male art students have better logical thinking skills than female art students. Similarly, male Commerce

Table 2. Descriptive statistics and t-test of gender

	Gender				t-value	p	Effect size
	Male (n=46)		Female (n=54)				
	M	SD	M	SD			
Logical thinking skills	35.3	6.07	34.22	7.00	-0.802	=.424	-0.161
Metacognitive skills	157.4	18.86	167.09	13.67	2.981	<.05	-0.153
Problem Solving Abilities	10.4	3.30	9.87	3.73	-0.764	=.447	0.598

Table 3. Descriptive statistics and F test (streams of the students)

	Streams			F-test	P	Effect size	Post hoc analysis
	Mean (SD)						
	Science (n=41) (1)	Arts (n=54) (2)	Commerce (n=5) (3)				
Logical thinking skills	35.15 (6.14)	34.59 (6.89)	32.40 (6.87)	0.403	0.670	0.008	
Metacognitive skills	165 (22.24)	161 (11.84)	158 (12.99)	0.543	0.596	0.013	
Problem Solving Abilities	10.05 (3.41)	10.56 (3.49)	6.00 (2.56)	6.06	<0.05	0.077	1>3, 2>3

Table 4. ANOVA – Logical thinking skills

	Sum of Squares	df	Mean Square	F	p	η^2
Gender	133	1	132.8	3.28	0.073	0.030
Stream	126	2	63.1	1.56	0.216	0.028
Gender * Stream	397	2	198.4	4.90	0.009	0.089
Residuals	3808	94	40.5			

Table 5. ANOVA – Metacognition skills

	Sum of Squares	df	Mean Square	F	p	η^2
Gender	138	1	138	0.554	0.459	0.005
Stream	250	2	125	0.500	0.608	0.010
Gender * Stream	2190	2	1095	4.388	0.015	0.084
Residuals	23460	94	250			

Table 6. ANOVA – Problem-solving abilities

	Sum of Squares	df	Mean Square	F	p	η^2
Gender	17.0	1	17.0	1.48	0.227	0.014
Stream	103.4	2	51.7	4.51	0.013	0.083
Gender * Stream	43.7	2	21.9	1.91	0.154	0.035
Residuals	1077.7	94	11.5			

students also show better logical thinking skills than their female counterparts. It means male and female students behave differently across different streams. Further, results from the categorized plot in Figure 2 demonstrate that female Science students have better metacognitive skills than male Science students. The results of female and male art students have followed a similar trend. However, male Commerce students show better meta-cognitive skills than their female counter. It depicts that the metacognitive skills of male and female students vary across different streams. Figure 3 depicts that male and female Science students do not differ in their problem-solving abilities. Art students also followed similar trends. However, male Commerce students have better problem-solving abilities than female students, but the difference is very less. Hence, students' performance across the stream does not depend on gender.

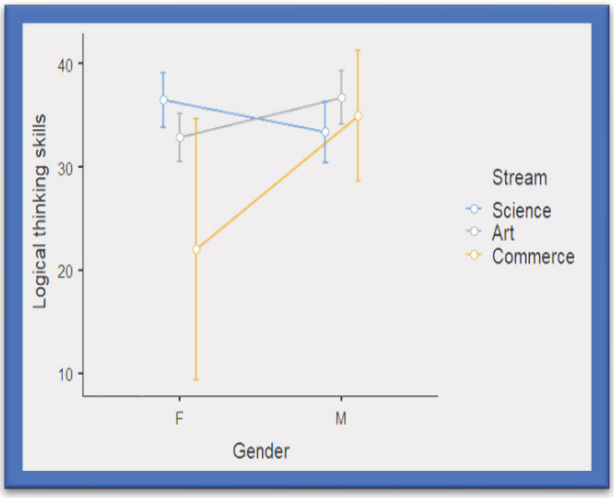

Figure 1: Mean Plot for Logical Thinking Skills

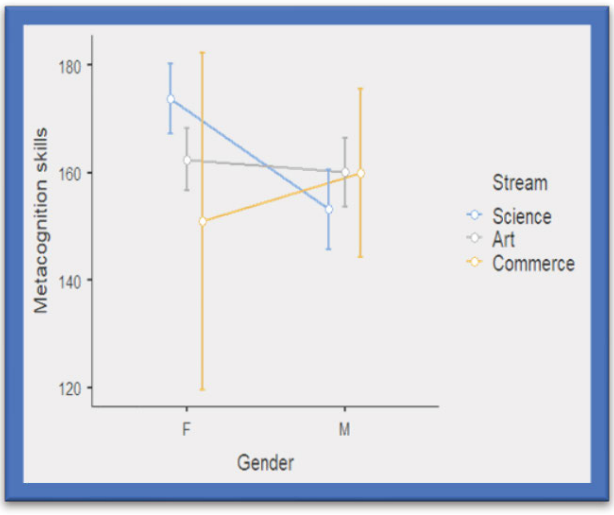

Figure 2: Mean Plot for Metacognitive Skills

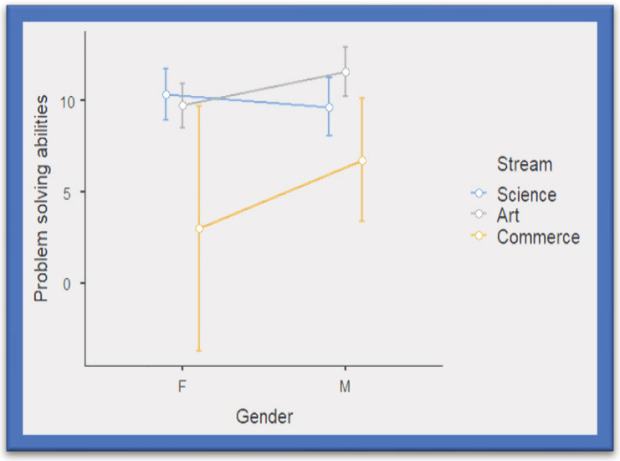

Figure 3: Mean Plot of meta-cognition for Problem Solving Abilities

RQ2: Explaining the association of metacognitive skills with logical thinking skills and problem-solving abilities

Pearson's correlation was calculated to investigate the association between the research variables. Results presented in Table 2 indicate that the coefficient of correlation (r) between logical thinking abilities and metacognitive skills is 0.278, which is positive and significant at the 0.01 level. Results also indicate that logical thinking is positively related to the meta-cognitive skills of these students. The correlation coefficient (r) between problem-solving abilities and meta-cognitive skills among senior secondary school students is 0.229, indicating a significant positive relationship between problem-solving abilities and metacognitive skills. Furthermore, the relationship between four subscales of metacognitive skills (planning skill, implementation skills, monitoring skills, and evaluation skills) with logical thinking skills and problem-solving abilities was analyzed. All the subscales are significantly correlated with each other (See Table 7). Planning skills (r=0.278,<.05) and implementation skills (r=0.398,<.05) have shown significant positive correlation with logical thinking skills while monitoring skills and evalution skills have shown weak correlation. Similar findings were also reported for problem-solving ability. This suggests that planning skills and implementation skills have stronger association with logical thinking and problem-solving skills.

RQ3: To what extent do metacognitive and logical thinking skills explain differences in problem-solving abilities?

A hierarchical regression analysis was conducted to explain how much variance in problem-solving abilities can be explained by logical thinking and metacognitive skills. In the first step, metacognitive skills were added; results showed that metacognitive skills significantly predicted problem-solving skills (R^2 = .042, F (1, 98) =5.44, p<0.05). Here, metacognitive skills explained 4.2% variance in problem-solving abilities. In step 2, logical thinking was run alone to explain variance in problem-solving abilities. Results depicted that logical thinking significantly predicts problem-solving abilities with 20.6% variance (R^2 = .206, F (1, 98)=26.6, p<.05). In step 3, metacognitive skills prediction became insignificant (b=0.02, t=1.172, p=0.244) when metacognitive skills and logical thinking ran together for regression analysis. This means that the effect of metacognitive skills on problem-solving abilities becomes insignificant in the presence of logical thinking skills. Hence, logical thinking skills may mediate between metacognitive skills and problem-solving abilities.

RQ4: Logical thinking as mediator and moderator

This research question was investigated using a moderator-mediation analysis, which asked whether logical thinking skills act as a mediator or moderator for the association between metacognitive skills and problem-solving abilities. The role of logical thinking as a moderator was analyzed using two-way ANOVA. Table 8 results from step 4 indicate that metacognitive skills (B=0.22, t=2.32, p<0.05) and logical thinking (B=1.19, t=2.62, p<0.05) significantly predicted problem-solving abilities and interaction term was also significant (B=-0.006, t=2.12, p<0.05). It demonstrates that logical thinking skills modify the relationship between metacognition and

Table 7. Coefficient of correlations (r) between different pairs of variables (logical thinking, meta-cognitive skills, and problem-solving abilities)

Variables	MCS	MCP	MCI	MCM	MCE	LTS	PSA
Metacognitive skills (MCS)	1						
Metacognitive planning skills (MCP)	0.872**	1					
Metacognitive implementation skills (MCI)	0.839**	0.673**	1				
Metacognitive monitoring skills (MCM)	0.838**	0.646**	0.627**	1			
Metacognitive evaluation skills (MCE)	0.817**	0.630**	0.594**	0.565**	1		
Logical thinking skills (LTS)	0.278**	0.398**	0.164	0.168	0.243*	1	
Problem-solving abilities (PSA)	0.229*	0.335**	0.156	0.026	0.279*	0.462**	1

Note. * p < .05, ** p < .01,

Table 8. Regression analysis summary on correlates of problem-solving abilities among senior secondary school students

Predictor	Estimate	SE	T	P
Step 1: R=0.229, R^2=0.0526, Adjusted R^2=0.0429, F (1,98) = 5.44, p=0.022				
Constant	2.3230	3.3602	0.691	0.491
Metacognition	0.0479	0.0206	2.333	0.022
Step 2: R=0.462, R^2=0.214, Adjusted R^2=0.206, F (1,98) = 26.6, p< .001				
Constant	1.501	1.6995	0.883	0.379
Logical thinking	0.248	0.0481	5.161	<.001
Step 3: R=0.47, R^2=0.225, Adjusted R^2=0.209, F (2, 97) = 14.1, p< .001				
Constant	-1.6422	3.1726	0.518	0.606
Metacognition	0.0228	0.0195	1.172	0.244
Logical Thinking	0.232	0.05	4.640	<.001
Step 4: R=0.509, R^2=0.2594, Adjusted R^2=0.2363, F (3, 96) = 11.21, p< .001				
Constant	33.64	15.402	2.18	0.031
Metacognition	0.22	0.0942	2.32	0.023
Logical Thinking	1.19	0.4559	2.62	0.01
Logical Thinking * Metacognition	-0.006	0.0028	2.12	0.036

problem-solving abilities. This means that as the level of logical thinking skills increases, so does the relationships between metacognitive skills and problem-solving abilities (see Figure 6). These findings imply that logical thinking skills has moderating role in the relationship of metacognitive skills (independent variable) and problem-solving abilities (dependent variable). Hence, in order to achieve desired level of problem solving ability one must achieve both metcognitive skills and logical thinking skills must be improved.

Further mediation analysis results shown in Table 9 demonstrated that the total effect of metacognitive skills on problem-solving abilities was significant (B=0.0479, t=2.33, p<.05). On the other hand, the direct effect of metacognitive skills on problem-solving abilities was insignificant (B=0.0228, t=1.19, p=.234). The indirect effect of metacognitive skills on problem-solving abilities was significant (B=0.0251, t=2.47, p.05). Furthermore, logical thinking is responsible for 52.4% of the mediation effect between metacognitive skills and problem-solving

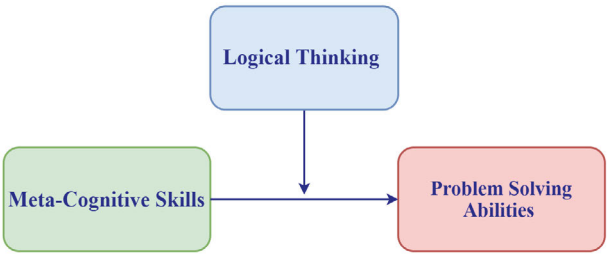

Figure 4: Moderation effect of logical thinking on the relationship between metacognitive skills and problem-solving abilities

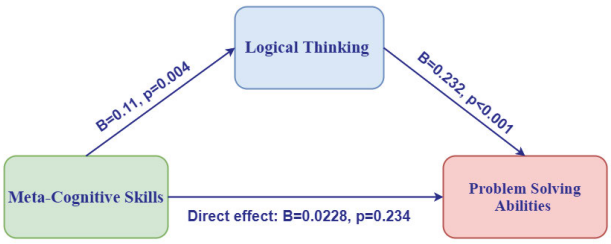

Figure 5: Mediation effect of logical thinking on the relationship between metacognitive skills and problem-solving abilities

Table 9. Mediation analysis results for the study variables

Effect	Label	Estimate	SE	T	P	% Mediation
Indirect	a × b	0.0251	0.0102	2.47	0.014	52.4
Direct	C	0.0228	0.0192	1.19	0.234	47.6
Total	c + a × b	0.0479	0.0203	2.36	0.018	100.0

Table 10: Path Estimates

Path			Label	Estimate	SE	Z	P
Metacognitive Skills	→	Logical Thinking	A	0.1083	0.0374	2.90	0.004
Logical thinking	→	Problem Solving Abilities	B	0.2320	0.0492	4.71	< .001
Metacognitive Skills	→	Problem Solving Abilities	C	0.0228	0.0192	1.19	0.234

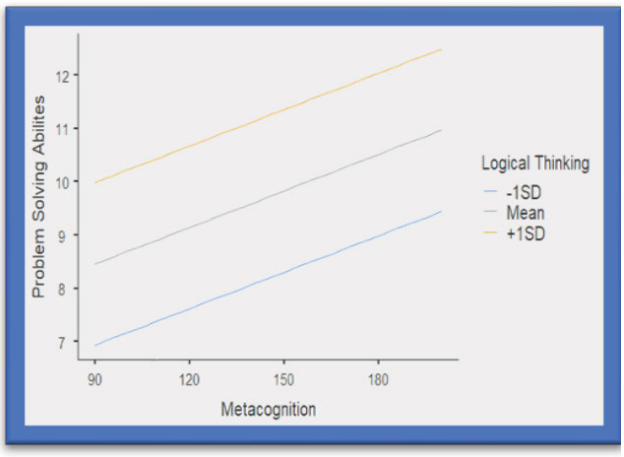

Figure 6: Moderation effect of logical thinking skills

abilities. This demonstrates that logical thinking skills completely mediate the relationship between metacognitive skills and problem-solving abilities. Figure 7 also clearly shows that higher the level of logical thinking skills and metacognitive skills, higher will be ability to solve problems.

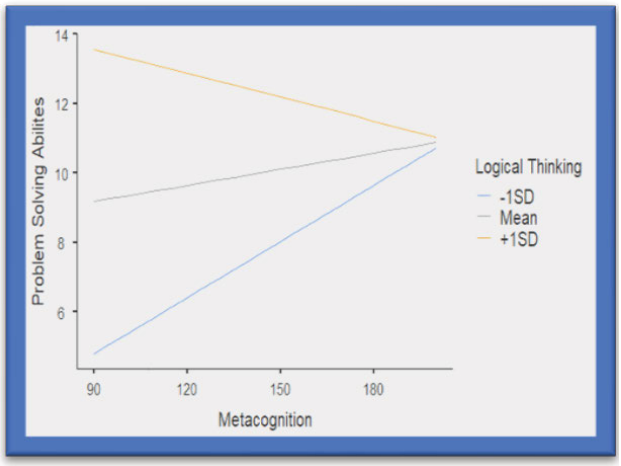

Figure 7: Mediation effect of logical thinking

DISCUSSION AND CONCLUSION

The present study found that most senior secondary school students' logical thinking skills, problem-solving abilities, and meta-cognitive skills vary from below-average to above-average. Similar findings were found in inferred quantitative results from previous studies, indicating that school students most likely lack metacognitive skills (Madang et al., 2020). The study's findings also suggested that logical thinking is related to the metacognitive skills of school students (Ku & Ho, 2010; Orion & Kali, 2005). Previous findings regarding relationship of metacognitive skills with problem-solving abilities are consistent with the present study (Efklides, 2005; Swanson, 1990). As the results show that metacognitive skills are positively related to logical thinking and problem-solving abilities among school students, resonating with the study of Vrugt & Oort (2008). Metacognitive skills significantly contribute to school students' logical thinking and problem-solving abilities (Milama et al., 2017). These findings support our mediation model that proposed logical thinking as the mediator between metacognition and logical thinking. Logical thinking also works as a mediator and moderator between metacognitive skills and problem-solving abilities. Results of the present study suggested that logical thinking skills work as moderator, which strengthens the association of metacognition on problem-solving abilities among school students. At the same time, mediation results showed that in the presence of logical thinking as a mediator, the association between metacognition and problem-solving abilities is likely to increase in a positive direction. Furthermore, the findings revealed that students with higher levels of metacognitive and logical thinking skills are better at problem-solving than students with lower levels of metacognitive skills.

Hence, there is significant evidence from the literature to support the significant contribution of logical thinking and meta-cognitive skills in determining the problem-solving ability among school students. Meta-cognitive skills help in improving logical thinking and increase higher-order thinking. School students' logical thinking skills enhance creative thinking and generate new ideas for solving problems (Norris and Phillips, 1987). Meta-cognitive skills can also help students in improving their learning process (Flavell, 1979). Kuhn (1999) also suggested that meta-cognitive skills increase students' problem-solving abilities and logical thinking. These skills also help in improving problem-solving ability (Vrugt & Oort, 2008) and logical thinking skills of school students (Knox, 2017).

The discussion above shows that developing meta-cognitive skills improves students' logical thinking and problem-solving skills. Moreover, logical thinking skills make students' minds more creative and innovative. These skills are very important for the overall growth and development of the student. The study results are important because they broaden our understanding by presenting the important role of logical thinking in the relationship between metacognitive skills and problem-

solving abilities. The mediation model reveals that the effect of metacognitive skills flows through logical thinking. It points out that along with improving metacognitive skills, teachers should focus on improving logical thinking to develop problem-solving abilities among students. Mediator analysis emphasizes that the development of metacognitive skills improves problem-solving abilites only if logical thinking skills are also developed. In the absence of logical thinking skills, the relationship between metacognitive skills on problem solving abilities will be weak. Hence, the study highlights the importance of improving metacognive skills in improving problem solving abilites using logical thinking skills. teachers must learn about different methods that support metacognitive development and problem-solving abilities (Aşık, & Erktin, 2019).

The study has certain certain limitations that need to be addressed in future research. First, it was based on a cross-sectional survey and therefore cannot make any statement on causality. Second, as this study is the first attempt to understand the mediating and moderating role of logical thinking skills in the relationship between metacognitive skills and problem solving abilities. In social sciences mediation models are considered to be the heart of theory development but still many researcher believe that the results of mediation model should be verified using experimental research in order to establish casuality. For better generalization, more studies with larger sample should be conducted and teaching implications of the study need to be studied.

Conflict of interest:The authors have no conflict of interest to disclose.

Data availability statement: The data presented in this study are available on request from thecor- responding author.

Ethics statement: This is a survey-based study and informed consent was obtained from all respondents who participated in the study.

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