Improving algebraic problem-solving achievement of secondary level students by using graph-based visualization of three models

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ABSTRACT

The study aims to investigate the algebraic problem-solving achievement (PSA) of secondary school students. The study is conducted to improve students' algebraic PSA by using the graphical visualization of three models, which are integrated to analyze certain factors that contribute to algebraic PSA. The first model is constructed to analyze students' intrinsic and extrinsic motivation in the prediction of algebraic PSA. The second model is constructed to analyze with the help of cognitive and affective self-concept. Also, the third model is constructed to analyze with the help of four factors, such as cognitive and affective self-concept, and intrinsic and extrinsic motivation. In this study, a descriptive survey design is used, in which 400 ninth-grade students are involved in the Morigaon District of Assam, India. The results of regression analysis in the first model explain 29.8% variance of algebraic PSA, the second model demonstrated that 64.9% variance of algebraic and the third model has highest 66.1% variance of algebraic PSA can be accounted by the linear combination of the four independent variables. The findings of this study can be utilized by secondary education institutions to improve students' mathematical achievement as a whole.

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1. INTRODUCTION

Mathematics is widely regarded as an essential skill with significant implications across various facets of life. It contributes to the development of a student's critical thinking and reasoning, as well as their fundamental problem-solving abilities, which are very useful in everyday life. Mathematics is a fundamental subject taught in schools from primary to secondary school around the globe. The role of mathematics is indispensable for a student at the secondary stage for their academic achievement, higher studies, and future pursuits [1]. Despite the importance of mathematics at this stage, students' achievement is not satisfactory [2]. In India, it has been considered one of the most challenging subjects in school and acts as the primary reason for students' failure at the secondary level. Many secondary school students find difficulty in solving a mathematics problem [3].

Algebra is a major area of mathematics dealing with symbols and numbers are mostly used in problem-solving. It occupies a major portion of the middle and secondary school mathematics curriculum. Algebraic knowledge improves students' critical thinking and problem-solving skills. The role of variables and constants must be understood in order to build mathematical reasoning and comprehension. However, there is a major challenge that students face while learning about variables and constants and interacting with algebra in general, as they do not know how quantities and variables relate to one another in algebraic expressions [4].

Algebraic problem-solving is a major facet of mathematics. In recent years, research has focused on algebraic problem-solving at secondary school [5]–[7]. Many factors associated with understanding of algebraic expressions and achievement in problem-solving such as students' self-concept, self-efficacy, motivation, experience in school, and attitudes [8]–[11]. Motivation and self-concept are the most influential factors that have positive connection with academic achievement at secondary level are to be investigated [12], [13]. According to Hammoudi [14], students' cognitive and affective self-concept and extrinsic motivation are the significant factors of mathematical achievement at undergraduate level. Also, Yildirim [15] demonstrated that while both intrinsic and extrinsic motivations have different mediation effects, they can both partially moderate the influence of teacher support on mathematics learning.

According to Lumsden [16], the willingness of students to engage in the learning process as well as the motives or goals that encourage students to take part or not in academic activities are referred to as student motivation. Motivation is one of the most crucial components for the learning and academic achievement of students [17]. Since motivation affects the instigation, way and intensity of cognitive processes, it is believed to be helpful to problem-solving [18]. According to Brophy [19], motivation is a cognitive process in the mathematical domain that involves grasping mathematical tasks, relating the information to prior knowledge, and becoming proficient in the mathematical abilities it supports. Students' motivation is the most important factor among many that determines how well they succeed in a mathematics course [20]. A substantial body of recent evidence has highlighted the association between motivation and mathematics achievement [21]–[23]. Moreover, Jing *et al.* [24] established the significant effect of motivation on learning algebra and algebraic achievement among Malaysian students. Also, according to the self-determination theory by Ryan and Deci [25], motivation can be categorized as extrinsic and intrinsic. The term "intrinsic motivation" describes the act of doing something because it is essentially fun or interesting. In contrast, "extrinsic motivation" motivates students to engage in academic activities due to external rewards like praise, awards, or punishments. The significant relationship between intrinsic motivation and mathematics achievement has been highlighted by several studies [26]–[28]. In a recent study, Tran and Nguyen [29] also established the positive relationship between intrinsic motivation and mathematics achievement. On the other hand, several other signifies the importance of extrinsic motivation in mathematical achievement [9], [30].

Research has identified students' mathematics self-concept as one of the most influential factors of mathematics achievement. In general, research has used the construct of self-concept as a measure of an individual's cognitive and affective abilities [12], [31]. The term "mathematics self-concept" describes how pupils view their own competency and capacity to acquire mathematics and do well on mathematical problems [32]. According to Tanner and Jones [33], students' cognitive self-concept is aware of their own mathematical knowledge, including their capacity to recognize their own mathematical strengths and limitations, link the various topics in the subject, and use their abstraction processes. The inner set of beliefs that students need to succeed in mathematics is known as their affective self-concept. These beliefs include their confidence in the nature of mathematical knowledge, their feelings of self-esteem as math learners, and their capacity to learn and achieve in the subject. Numerous studies have established the positive relationship between mathematics self-concept and mathematics achievement [5], [34]. For instance, Abdullah *et al.* [5] established the relationship between self-concept, emotional intelligence, and problem-solving skills and attitudes towards solving algebraic problems among Nigerian secondary school students. According to their findings students' problem-solving skills can be developed by taking into account of their self-concept and emotional intelligence. In another study, Hammoudi and Grira [9] established that students' cognitive and affective self-concept have a significant influence on motivation for their mathematical achievement.

The substantial body of the discussed literature indicates students' motivation and self-concept are crucial factors in their success in mathematics. Though a lot of research has been done concerning to the effect of students' motivation and self-concept on mathematics achievement, little study has explored algebraic problem-solving. Moreover, the relationship between intrinsic motivation, extrinsic motivation, cognitive self-concept, affective self-concept, and algebraic problem-solving has not been explored in detail. This study examines the effect of self-concept and motivational aspects on algebraic problem-solving achievement (PSA). Based on the objectives, the following three mathematical models are constructed to improve students' algebraic PSA by using graph-based visualization of the three models. These models are combined to analyze students' algebraic PSA with the help of their self-concept and motivational aspects.

In the first model, it is catalyzed to examine the significant association of algebraic PSA and the two aspects of motivation. In educational research, students' motivation is the important factors [20], [21] and mathematical achievement can be associated to both intrinsic and extensive motivation. According to study by Ryan and Deci [35], intrinsic motivation is not sufficient to engage in or enjoy a specific task without extrinsic motivation. Thus, it may be hypothesized that students learning mathematics are motivated intrinsically for their interests and extrinsically in order to take advantage of future prospects.

Since solving algebraic problems is a necessary aspect of mathematics learning, it is hypothesized that students' intrinsic and extrinsic motivation may have an impact on their ability to solve algebraic problems. For this purpose, the following two hypotheses are created to examine students' algebraic PSA. The following two hypotheses are examined by using the first model's performance:

- H_0^1: there is no relationship between students' intrinsic motivation and algebraic PSA.
- H_0^2: there is no relationship between students' extrinsic motivation and algebraic PSA.

The second model aims to examine the aspects of self-concept, in relation to algebraic PSA. According to Arens *et al.* [36], cognitive self-concept is one's perception and beliefs about their own abilities, skills, and knowledge in mathematics. It involves beliefs about one's problem-solving abilities, understanding of mathematical concepts and overall competence in mathematics. In educational studies, cognitive self-concept is the most important factor in mathematical achievement. Also, the affective self-concept in mathematics pertains to emotional perceptions and attitudes towards mathematics [37]. Students' positive affective self-concept can enhance learning and achievement in mathematics [10]. Thus, both cognitive and affective self-concepts might considerably influence on student's approach and success in mathematical tasks.

In light of this, it is possible to hypothesize that student' affective and cognitive self-concept might be linked to mathematical PSA. For this purpose, the following four hypotheses are created to examine students' algebraic PSA. The following two hypotheses are examined by the second model's performance:

- H_0^3: there is no relationship between students' cognitive self-concept and algebraic PSA.
- H_0^4: there is no relationship between students' affective self-concept and algebraic PSA.

According to Kaplan [27], strategies such as boosting extrinsic and intrinsic motivation and developing a good self-concept through improving intrinsic motivation should be given priority in order to improve mathematical achievement. By emphasizing these approaches, students are encouraged to explore math, set goals, and build confidence, ultimately leading to greater success in the subject. Furthermore, Hammoudi [14] points out that the most significant variables for mathematics achievement at the undergraduate level are students' self-concepts and their motivational aspects. Hence, the third model is created to investigate the influence on algebraic PSA of the four factors, such as students' cognitive self-concept, affective self-concept, intrinsic motivation and extrinsic motivation. For this purpose, the following four hypotheses are created to predict students' algebraic PSA. The following hypotheses are examined by the third model's performance:

- H_0^5: there is no relationship between students' intrinsic motivation and algebraic PSA.
- H_0^6: there is no relationship between students' extrinsic motivation and algebraic PSA.
- H_0^7: there is no relationship between students' cognitive self-concept and algebraic PSA.
- H_0^8: there is no relationship between students' affective self-concept and algebraic PSA.

2. RESEARCH METHOD

A quantitative research design is used for this present study. In this study, a variety of regression tests have been used to examine the relationship between multiple independent variables and a single dependent variable for the effectiveness of each of the models. For the study, a sample of 400 ninth-grade pupils is randomly selected from the Morigaon District of Assam. This sample size is determined using Cochran's sample size formula (for finite population).

Three instruments are used to collect the data. The instruments are the motivation scale, the self-concept scale, and algebraic PSA test. The motivation scale is adopted and modified from Hammoudi [14] for the study. The scale consists of 10 items: five for intrinsic and five for extrinsic motivations. One example of intrinsic motivation is "mathematics is mainly about facts and operations," and one example of extrinsic motivation is "learning mathematics is useful for me because it will improve my career prospects." The Likert 5-point scale is used for the study. It ranges from strongly disagree=1 to strongly agree=5. The Cronbach alpha reliability of the motivational scale is 0.815.

The self-concept scale is adopted from Hammoudi [14]. The self-concept scale consists of 10 items: six for "cognitive self-concept" and four for "affective self-concept" on the Likert five-point scale. One example of cognitive self-concept is "I believe I have a good understanding of mathematical concepts," and one example of affective self-concept is "I feel confident in my mathematical problem-solving skills, even when the problems are difficult." The Likert 5-point scale is used for the study. It ranges from strongly disagree=1 to strongly agree=5. The Cronbach alpha reliability of the motivational scale is 0.901.

Students' algebraic PSA is measured by a test. It consists of 20 multiple choice items based on the class IX syllabus. The reliability of the items is calculated by using Cronbach alpha, which is 0.89 and is in an acceptable range. An example of the test item is “the co-efficient of x^2 in the expansion of (2x-3) (x^2-3x+1) is”: (i) 9, (ii) -9, (iii) 1, and (iv) -1.

The collected data are analyzed by using SPSS 26.0 version. Regression analysis is done to test the performance of each of the three models. Students’ algebraic PSA is the dependent variable in all the three models. Also, distinct independent variables are used for each of the three models. The accuracy of each model is predicted using the coefficient of determinant (R^2). It determines how well the data points fit the regression line.

3. RESULTS

The results presented in Tables 1-3 have been used to examine the correlation of algebraic PSA with the two aspects of motivation. From Table 3, it is seen that extrinsic motivation (b=1.490, t=3.262, p<0.001) and intrinsic motivation (b=3.393, t=6.640, p<0.000) has significant relationship with algebraic PSA. Hence, the hypotheses H_0^1 and H_0^2 have been rejected.

Also, from Tables 1 and 2, it is found that algebraic PSA can be explained by both the intrinsic and extrinsic motivations, as F (2, 397) =85.328, p<0.000. The value of the coefficient of determination (R^2=0.298) shows that cognitive and affective self-concept explains 29.8% of the variation of algebraic PSA. Also, the multiple correlation coefficient (R=0.546) indicates that students’ intrinsic and extrinsic motivation are significantly associated to algebraic PSA.

Table 1. Model I summary

Model	R	R^2	Adjusted R^2	Standard error of the estimate
1	0.546[a]	0.298	0.295	0.452243

[a]Predictors: (constant), extrinsic motivation, intrinsic motivation

Table 2. Model I ANOVA[a]

Mode I	Sum of square	df	Mean square	F	Sig.
1 Regression	3449.400	2	1724.700	85.328	0.000[b]
Residual	8119.578	397	20.452		
Total	11568.977	399			

[a]Dependent variable: PSA
[b]Predictors: (constant), extrinsic motivation and intrinsic motivation

Table 3. Model I coefficients[a]

Model	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Standard error	Beta (β)		
1 (constant)	-4.636	2.275		-3.637	0.000
Extrinsic motivation	1.490	0.457	0.193	3.262	0.001
Intrinsic motivation	3.393	0.511	0.393	6.640	0.000

[a]Dependent variable: PSA

Figure 1 indicates that students’ intrinsic motivation (β=0.393) in mathematics has a greater effect on algebraic PSA than extrinsic motivation (β=0.193) and both the independent variable have 29.8% combined variation explanation on algebraic PSA. The first analytical model is presented in Figure 1. The linear regression model is constructed as in (1).

$$Y = -4.636 + 1.490\,X1 + 3.393\,X2 + \varepsilon \quad (1)$$

Where, Y=algebraic PSA, X_1=extrinsic motivation, X_2=intrinsic motivation, and ε=model’s error.

The results presented in Tables 4-6 has been used to examine the correlation of algebraic PSA with the two aspects of self-concept. From Table 6, it is seen that cognitive self-concept (b=5.548, t=12.225, p<0.000) and affective self-concept (b=2.083, t=5.119, p<0.000) has significant relationship with algebraic PSA. Hence, the hypotheses H_0^3 and H_0^4 have been rejected.

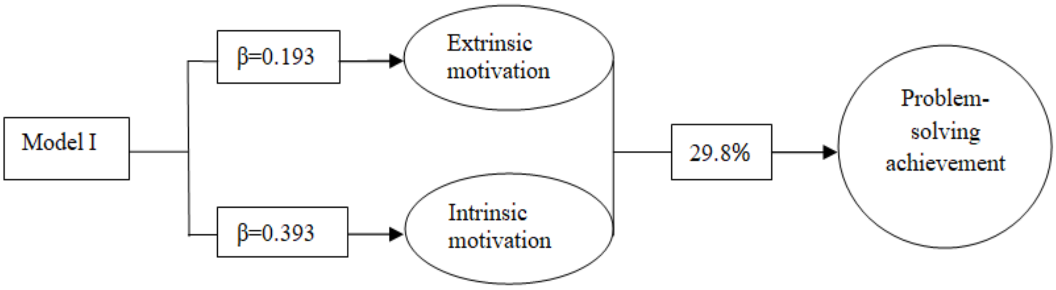

Figure 1. Graph-based visualization model I

Table 4. Model II summary

Model	R	R^2	Adjusted R^2	Standard error of the estimate
2	0.806[a]	0.649	0.647	0.319831

[a]Predictors: (constant), affective self-concept, cognitive self-concept

Table 5. Model II ANOVA[a]

Model	Sum of square	df	Mean square	F	Sig.
2 Regression	7507.991	2	3753.997	366.989	0.000[b]
Residual	4060.987	397	10.229		
Total	11568.977	399			

[a]Dependent variable: PSA
[b]Predictors: (Constant), affective self-concept, cognitive self-concept

Table 6. Model II coefficients[a]

Model	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Standard error	Beta (β)		
2 (constant)	-11.112	0.878		-12.658	0.000
Cognitive self-concept	4.548	0.372	0.594	12.225	0.000
Affective self-concept	2.083	0.407	0.249	5.117	0.000

[a]Dependent variable: PSA

Also, from Tables 4 and 5, it is found that algebraic PSA can be explained by both the predictor variable cognitive and affective self-concept as F (2,397)=366.989, p<0.000. According to the coefficient of determination (R^2=0.298), the predictor cognitive and affective self-concept explains 29.8% variation of algebraic PSA. Also, the multiple correlation coefficient (R=0.806) shows that students' cognitive and affective self-concept are significantly associated to algebraic PSA.

Figure 2 indicated that students' cognitive self-concept (β=5.594) in mathematics has a greater effect on algebraic PSA than affective self-concept (β=2.249) and both the independent variable have 64.9% combined variation explanation on algebraic PSA. Based on the analytical model in Figure 2, the regression equation is presented in the (2).

$$Y = -11.112 + 5.548\,X1 + 2.083\,X2 + \varepsilon \quad (2)$$

Where, Y=algebraic PSA, X_1=cognitive self-concept, X_2=affective self-concept, and ε=model's error.

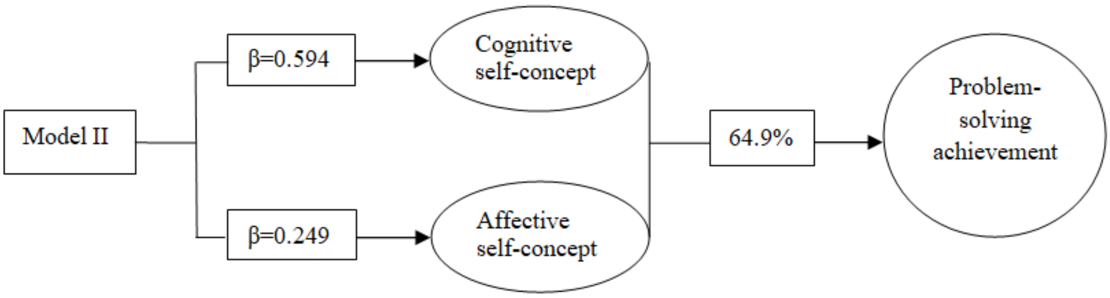

Figure 2. Graph-based visualization model II

Tables 7-9 provide the estimate of the proposed regression model, which demonstrates the relationship between algebraic PSA and students' cognitive self-concept, affective self-concept, intrinsic and extrinsic motivation. From Table 9, it is seen that student's cognitive self-concept (b=4.023, t=10.220, P<0.000), affective self-concept (b=2.025, t=5.033, P<0.000) and intrinsic motivation (b=0.986, t=2.619, P<0.009) has significant effect on algebraic PSA. Thus, the hypotheses H_0^5, H_0^6, and H_0^7 are rejected, but the hypothesis H_0^8 is accepted.

Table 7. Model III summary

Model	R	R^2	Adjusted R^2	Standard error of the estimate
3	0.813[a]	0.661	0.657	0.315257

[a]Predictors: (constant), intrinsic motivation, extrinsic motivation, cognitive self-concept and affective self-concept

Table 8. Model III ANOVA[a]

Model	Sum of square	df	Mean square	F	Sig.
3 Regression	7643.184	4	1910.796	192.258	0.000[b]
Residual	3925.794				
Total	11568.977				

[a]Dependent variable: PSA
[b]Predictors: (constant), intrinsic motivation, extrinsic motivation, cognitive self-concept and affective self-concept

Table 9. Model III coefficients[a]

Model	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Standard error	Beta (β)		
3 (constant)	-12.947	1.003		-12.902	0.000
Cognitive self-concept	4.023	0.394	0.526	10.220	0.000
Affective self-concept	2.025	0.402	0.242	5.033	0.000
Intrinsic motivation	0.986	0.377	0.114	2.619	0.009
Extrinsic motivation	0.176	0.325	0.023	0.541	0.589

[a]Dependent variable: PSA

The third model is shown in the graphical visualization in Figure 3. From Figure 3, it is seen that cognitive self-concept has the highest contribution to algebraic PSA with β=0.526. The second largest predictor is affective self-concept with β=0.242, followed by intrinsic motivation with β=0.114 and extrinsic motivation β=0.023. The variation of algebraic PSA is explaining by these four variables is 66.1%. The 3rd analytical model is presented in Figure 3. The regression model is constructed as in (3).

$$Y = -12.947 + 4.023\,X1 + 2.025\,X2 + 0.986\,X3 + 0.0176\,X4 + \varepsilon \quad (3)$$

Where, Y=Algebraic PSA, X_1=cognitive self-concept, X_2=affective self-concept, X_3=intrinsic motivation, X_4=extrinsic motivation, and ε=model's error.

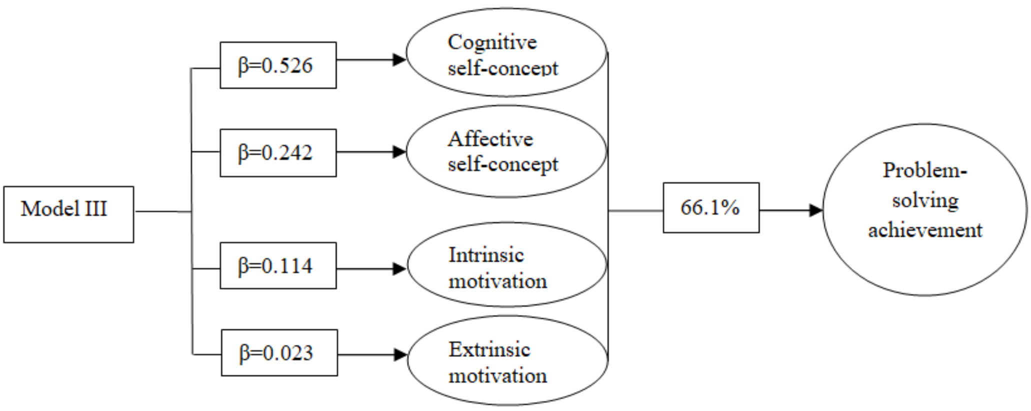

Figure 3. Graph-based visualization model III

4. DISCUSSION

In order to conduct this study, three mathematical models are constructed, and they are anticipated to improve students' algebraic PSA. The most important finding is that the graphical representation of the three combined models shown in Figure 4. The combined models indicate that model III has higher performance in explaining students' algebraic PSA. The independent factors in model III explain 66.1% of the variance of the algebraic PSA, as seen in Figure 4. However, in models I and II, the independent variables explain 64.9% and 29.8%, respectively, of the variation of algebraic PSA.

Figure 4 shows that 29.8% of the variation in algebraic PSA can be explained by the two factors, intrinsic and extrinsic motivation. It indicates that students' intrinsic and extrinsic motivation have a significant relationship with algebraic PSA. This finding is consistent with the fact that students' intrinsic and extrinsic motivations are the significant factors of mathematical achievement [26], [29].

As shown in Figure 4, the two self-concept aspects of mathematics explain 64.9% of the variation of algebraic PSA. Thus, fostering cognitive and affective self-concept in mathematics can improve algebraic PSA. Previous research supports that considering students' self-concept in the mathematical realm helps them solve algebraic problems more successfully and motivated to learn [5], [11]. Also, Jing *et al.* [24] point out that the students' motivation for learning algebra and algebraic achievement is most significant. Hence, it suggests that students' positive self-concept about their ability to solve a problem may lead them to engage in mathematical tasks, which may increase their competency and capacity to perform well in mathematical problem-solving [33]. They are also motivated to do well and put greater effort in mathematical tasks [19].

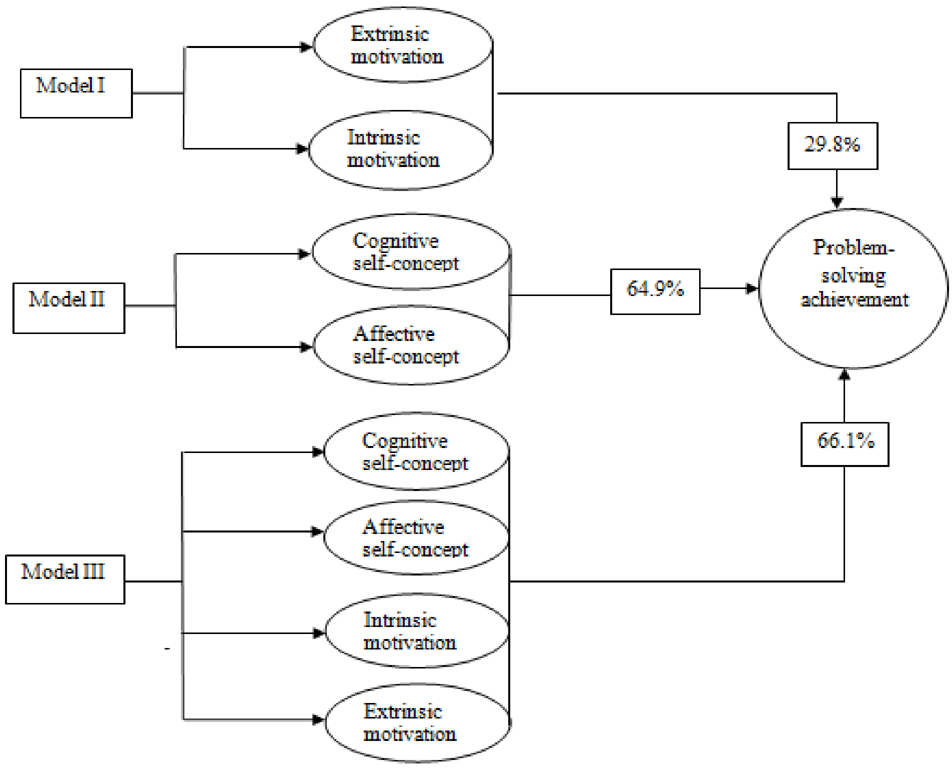

Figure 4. Graph-based visualization of three integrated models

In Figure 4, the four predictors (cognitive and affective self-concept as well as intrinsic and extrinsic motivation) explain 66.1% of the variation in algebraic PSA. The four independent variables all together have a significant relationship with algebraic PSA. The findings in model III, evidence that the cognitive self-concept is the best predictor of algebraic PSA. Also, affective self-concept has a higher contribution to algebraic PSA than intrinsic and extrinsic motivation. On the other hand, extrinsic motivation has found a weak association with algebraic PSA. This finding is consistent with Hammoudi and Grira [9] that students' cognitive and affective self-concept have a stronger effect on their mathematical achievement than extrinsic motivation. Furthermore, Hammoudi and Grira [10] emphasized the significance of both extrinsic and intrinsic motivation for achievement in mathematics. But, according to our findings, only intrinsic motivation has a significant contribution to algebraic PSA, which supports several studies [26]–[28] and contradicts the findings of several others [9], [30]. Therefore, a positive cognitive and affective self-concept combined with intrinsic motivation can greatly affect students' cognitive and affective behavior to improve and succeed in algebraic problem-solving.

5. CONCLUSION

The study is designed to improve algebraic PSA among secondary school students. Three models are used and integrated to analyze the contribution of certain factors that helps in improving algebraic PSA. The results of model I show that 29.8% of the variance of algebraic PSA can be explained by the linear combination of students' intrinsic and extrinsic motivation. The results of model II demonstrated that 64.9% variance of algebraic PSA can be accounted by the linear combination of students' cognitive and affective self-concept. Also, in model III, it is seen that the highest 66.1% variance of algebraic PSA can be explained by the linear combination of the four independent variables.

Based on the findings of the model III, it shows that students' cognitive and affective self-concept have higher contribution on algebraic PSA followed by intrinsic and extrinsic motivation. Therefore, in light of the results, the following suggestions are provided to educators, policymakers, and stakeholders to improve students' algebraic problem-solving at the secondary level: i) enhancing students' cognitive self-concept in mathematics by assessing their belief in mathematics, willingness to engage in mathematical tasks, consistent practice to build self-confidence and focus on algebraic problem-solving activities; ii) boosting students' affective self-concept in mathematics by building positive feelings, attitudes and beliefs towards mathematical problems; iii) encouraging and fostering intrinsic motivation is essential for cultivating a genuine passion for mathematics learning and fostering long-term success in problem solving; and iv) extrinsic motivation can significantly impact mathematics problem-solving abilities by influencing students' engagement, effort, and persistence. When students are extrinsically motivated, they may be more likely to tackle challenging mathematical problems; stay focused on tasks for longer periods and seeks out additional resources or support to solve problems.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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Samiran Das		✓		✓		✓				✓	✓	✓	✓	

C : **C**onceptualization	I : **I**nvestigation	Vi : **Vi**sualization
M : **M**ethodology	R : **R**esources	Su : **Su**pervision
So : **So**ftware	D : **D**ata Curation	P : **P**roject administration
Va : **Va**lidation	O : Writing - **O**riginal Draft	Fu : **Fu**nding acquisition
Fo : **Fo**rmal analysis	E : Writing - Review & **E**diting	

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author [IA]. The data, which contain information that could compromise the privacy of research participants, are not publicly available due to certain restrictions.

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