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An investigation into the common errors and misconceptions that students commit in MTH 1101 - Algebra at the University of Guyana, Turkeyen Campus

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Abstract:
It is possible that errors and misconceptions that students commit in examinations are among the leading factors that negatively affect their performance. This research investigated common errors and misconceptions that students are prone to commit in MTH 1101 – Algebra, their frequencies and how they affect their performance. This study adopted a descriptive survey design and involved one hundred and ten students from the MTH 1101 - Algebra class (2019/2020). Data was collected through a survey in the form of a test. The analysis revealed that students had the greatest difficulty in performing operations on algebraic fractions as well as reporting all the solutions to an algebraic equation problem set. Other common errors included the inability to: translate a word problem into its correct algebraic representations; manipulate a negative coefficient in an inequality; manipulate indices and solve for both variables in a system simultaneous equation. The analysis also incorporated a count on questions that students avoided, the most evident ones are solving a pair of simultaneous equations, solving an inequality and manipulating algebraic fractions. Additionally, a score comparison of the test results revealed that students who made a particular error or misconception scored worse than those who did not.

Key Words: *Algebra; Error; Misconception; Performance; Expression; Equation; Word Problem.*

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I. Introduction

Algebra is considered to be a very important branch of Mathematics. Without Algebra, one cannot be successful in Mathematics (Makonye & Stepwell, 2016, as cited in Fumador & Agyei, 2018) nor clearly understand the essential mathematical concepts in Science, Technology, Statistics or Business (Katz, 2007, as cited in Fumador & Agyei, 2018). This is indicative that a good understanding of Algebra is required for prerequisite for students' success in advanced level Mathematics (Usisin, 2004, as cited in Fumador & Agyei, 2018). Moreover, first-year Algebra in colleges and universities serves as a foundation course in determining whether students can go on to do advanced courses in Engineering and Natural and Applied Sciences (Adelman, 2006, as cited in Booth, Barbieri, Eyer, & Paré-Blagoev, 2014). MTH 1101 – Algebra is a course for first-year students in a mathematical or related program at the University of Guyana, Turkeyen Campus. This course provides a solid foundation for furthering studies in the faculties of Natural Sciences, Health Sciences, Education and Humanities, and Earth and Environmental Studies. Despite its importance, many students are affected by conceptual difficulties in this course.

According to Reyes (2010) as cited in Jaster (2013), in higher education, algebraic problems that encompasses errors and misconceptions are especially worrying because they can lead to students' poor performance. We must be cognizant of the fact that Algebra is viewed as a required foundation course for various majors in universities which controls students' access to their degree completion. Dugopolski (2010) as cited in Jaster (2013) pointed out that in higher education, Algebra makes available the skills, theoretical understandings and insights needed for success in follow-up courses in universities. Wang (2015) added that Algebra has been well-thought-out as a benchmark for students when it comes to learning mathematics.

Rushton (2014) indicated that when answering algebraic questions, students often make errors leading to incorrect answers which would lead to the loss of marks. However, most of the times, errors that are evident in students' scripts are referred to as common algebraic errors. Confrey (1990) as cited in Rushton (2014) suggested that both errors and misconceptions occur as a result of incorrect rules and beliefs that students hold, but also proposed that misconceptions are attached to particular theoretical positions. Researchers have recognized that students create barriers in formal algebraic systems and algebraic problem solving due to errors and misconceptions (Kieran, 1992, as cited in Wang, 2015). Moreover, Chamundeswari (2014) explained that if students do not have a profound understanding of the mathematical concepts, they will find themselves making errors in algebraic operations and computations.

Over a seven-year period (2012 – 2019), it was observed, through statistics, that there is a high failure rate in the first year course, MTH 1101 – Algebra, at the University of Guyana, Turkeyen Campus. Therefore, this present study is to investigate the common errors and misconceptions as one of the factors that can negatively affect students' performance in MTH 1101- Algebra. It is intended to identify the common errors and misconceptions that students make, identify the frequencies of these common errors and misconceptions and determine how they negatively affect students' performance. Based on the findings of this study, it is expected that students will be enlightened on the errors and misconceptions they commit and how their performance are negatively affected.

II. Materials and Methods

This study employed a descriptive survey design which was characterized by the collection and analysis of quantitative data. The independent variable was the types of errors and misconceptions that students commit in MTH 1101 - Algebra while the dependent variable was the students' performance. This was supported by Orodho (2005), who stated that descriptive survey should be used to investigate if there is relationship between these two variables.

The target population for this study incorporated all the students of the first year course MTH 1101- Algebra at the University of Guyana, Turkeyen Campus. On average, students' enrollment for this class is approximately five hundred students. From the student enrollment, a sample of one hundred and ten (22%) students was randomly selected from groups stratified on the basis of MTH 1101- Algebra tutorials. According to Gorard (2001), a sampling fraction of between ten to twenty percent of target population in descriptive research is deemed acceptable.

A paper and pencil test was used as the research instrument to collect quantitative data since it allows for exam-type monitoring while being administered. The paper and pencil test consisted of twenty short structured-type questions which were of average difficulty. It reflected a wide coverage of the course content as it relates to expressions, equations and inequations and words problems that enabled this study to capture the common types of errors and misconceptions students committed in MTH 1101- Algebra. The test was marked using a detailed marking scheme and the correct responses, the types of errors and misconceptions committed, the incorrect responses (those that were not applicable to the common types of errors and misconceptions) and no response to questions were recorded. The data was then encoded and stored in an excel file.

Technique used for data analysis

The excel file containing the data from the test was read into the R statistical software for analysis. A score was calculated for each student based on the number of errors and misconceptions, non-response items and missing items from the maximum score. Different data files were made for each respective objective addressed in the discussion. The proportion and frequency graphs were created from each respective data files. Tables containing the information was exported to an excel file. At this point the common errors and misconceptions were identified.

The population distribution for scores of the test items tend to be normally distributed, thus, making the t-test for difference of means applicable. A power analysis was used to decide whether the data was sufficient for the defined difference in score. The assumptions for the t-test were checked as such:

a) Normality using a quantile plot. Where this assumption wasn't met the non-parametric Mann Whitney test was used.
b) A check for outliers using a boxplot. Test items had no more than one outlier which was considered to be valid data.
c) Levene's test for equality of variance was used to check whether the homoscedasticity assumption was met. Where this assumption was not met, the Welch's t-test was used.

III. Results

Data analysis of performance

Even though MTH 1101 - Algebra is an essential foundation course at the University of Guyana, Turkeyen Campus, yet a large percentage of students would fail to succeed annually. As a result, many students are prevented from continuing their program of studies since MTH 1101 - Algebra serves as a prerequisite course for other courses in the faculties of Natural Sciences, Health Sciences, Education and Humanities, Earth and Environmental Studies. Students who fail MTH 1101 – Algebra are advised to re-do the course in the recess period which comes with an additional cost or await the next academic year to repeat the course.

Table 1: Performance results of students in MTH 1101 - Algebra

Academic Year	Total Number of Scripts	Number of Grades A-D and Percentage Pass		Number of Grade F and Percentage Fail	
2012/2013	336	196	58.3%	140	41.7%
2013/2014	398	232	58.3%	166	41.7%
2014/2015	364	236	64.8%	128	35.2%
2015/2016	361	259	71.7%	102	28.3%
2016/2017	416	217	52.2%	199	47.8%
2017/2018	427	199	46.6%	228	53.4%
2018/2019	492	304	61.8%	188	38.2%
Average		59.1%		40.9%	

Table 1 shows the performance of students, over a seven-year period (2012 – 2019), in MTH 1101 – Algebra at the University of Guyana, Turkeyen Campus. It can be observed that there is an average failure rate of 40.9% over the seven-year period. According Eng, Li Li and Julaihi (2008), a high-failure rate course is a course that has an average pass rate below 70% across seven years. From this study, there is an average pass rate of 59.1% across the seven academic semesters in seven consecutive years, which is indicative that there is a high failure rate in MTH 1101-Algebra at the University of Guyana.

Data analysis of common errors and misconceptions committed by students in MTH 1101-Algebra

An analysis of the common errors and misconceptions was conducted from four perspectives. The first considered the failure proportions for all participants of the study. The second, for those who scored considerably well, as it is interesting to note any consistency in the errors and misconceptions made by high performing students. The third view is for students who scored poor to moderately well in order to note the mistakes an average student makes. Students who performed very poorly will not be examined in detail as their failure rates are simply high for the majority of questions; the information to be gained from investigating this score range would be where not to focus efforts in case there are errors and misconceptions that students does not make. The final view will be investigating the proportion of students who did not give a response to a particular question as it may give an idea of the kind of questions students tend to avoid. The common errors and misconceptions are found by tabulating the frequencies and calculating the proportion of students who make the particular error. How making the error or misconception affects the grade profile is investigated by comparing the mean scores of students who make the error or misconception to those who did not. It is to be noted that although an error or misconception accounts for only one point thereby limiting the effect it can have on the overall score, the magnitude of the difference may help to assign a level of importance to the common error or misconception to mean that students who make this mistake also tend to make many other mistakes; thus by focusing on such an error or misconception the score on students who score the worse can be targeted first. In addition, for this study a common error or misconception is defined to be an error or misconception that is made by at least fifty percent of the group under consideration.

Figure 1: Overall group response

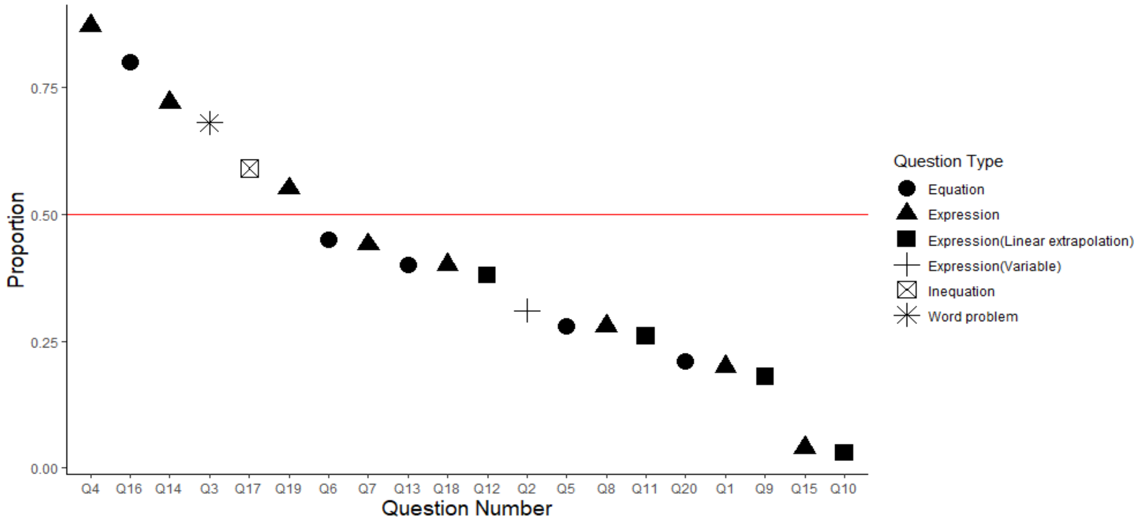

Figure 1 depicts the overall group response in the test. The total number of respondents is one hundred and ten, having a mean number of valid reponses for the questions being ninety four with a standard deviation of fourteen. Questions six and eleven have deviations from this trend with mean number of valid reponses being fifty three and seventy two respectively. These are not alarming deviations. It would seem that for both equation and expression type questions the difficulty experienced by the group varied greatly. The linear extrapolation questions were handled fairly well with the highest overall failure proportion being thirty eight percent. Although these questions show variability, the error proportions are within the tolerable range for the items. The group had difficulty with the word and inequation type questions which experienced a sixty eight and fifty nine percent failure proportions respectively. Athough these types have only one question each on the test item, they have some of the highest failure rates in the group. The expression variable question type was also handled fairly well given the failure proportion of thirty one percent.

Table 2: Problematic questions for the overall group

Question	Type	Error Proportion	Error/Misconception
Q4	Expression	0.87	Incorrect cancellations by use of inappropriate rules in simplifying an algebraic fraction
Q16	Equation	0.80	Omitting the negative sign in front of the square root symbol - losing a solution
Q14	Expression	0.72	Incorrect simplification of a rational expression due to undistributed cancellations
Q3	Word problem	0.68	Error in translating a story into an appropriate algebraic equation and solving it
Q17	Inequation	0.59	Error in manipulating a negative coefficient of a variables across an inequality sign
Q19	Expression	0.55	Incorrect numerator or denominator (LCM) when adding two algebraic fractions

Table 2 shows the problematic questions for the ovrall group in order of difficulty. These difficulties include: problems with reducing algebraic fractions to their lowest forms; negligence in reporting all solutions for an equation with more than one solution; difficulty translating a word problem into algebraic equation; how to deal with division by negative numbers in an equality and manipulaion on algebraic fractions.

Figure 2: High performing perspective

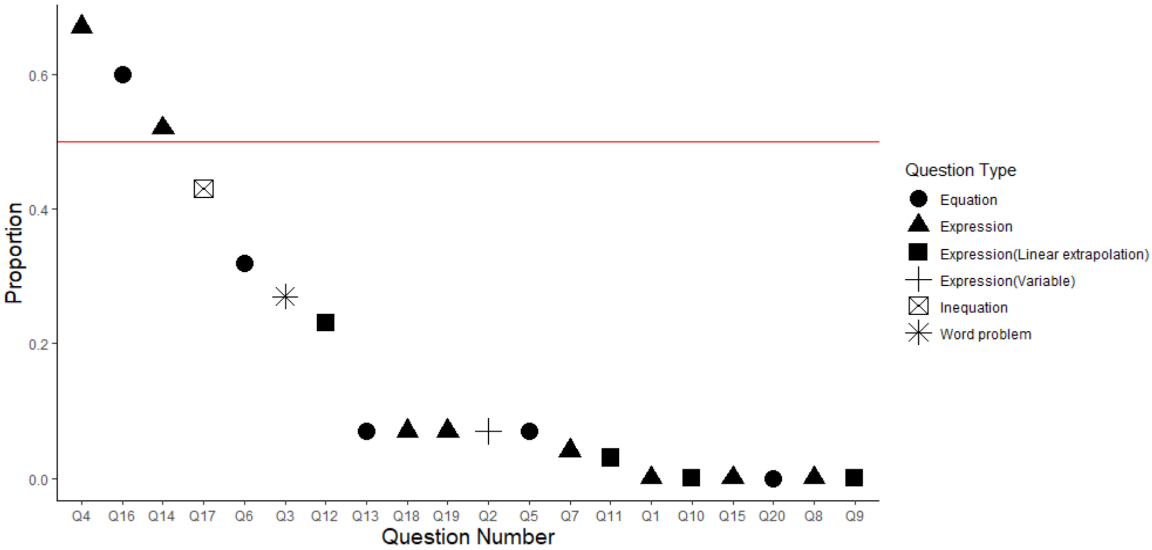

Figure 2 depicts the high perfoming perspective in which the score for students considered to have done well is at least fourteen out of twenty (70%). A total of thirty students met this criterion with the mean number of valid responses being twenty eight with a standard deviation of two. Question seven is a concerning deviation from this trend as its number of valid responses is twenty three.Thirteen of the questions the students handled very well. From the Fig. 2, there is a clear distinction to see where questions were starting to become problematic. Of this set, there is a mix of the question types. Both questions four and fourteen are based on simplifying algebraic fractions which require the prerequisite knowledge of identifying the highest common factors and performing the process of factorization. In question four, students were required to factorize the numerator of a simple algebraic expression (fraction) and do the necessary cancellations. However, question fourteen was more difficult as it required students to first identify the highest common factor in the numerator to performed factorization in order to simplify the rational expression. In both cases, students experienced difficulty in factorizing the rational expressions and simplifying them. In addition, question sixteen involved students solving a quadratic equation in the form $ax^2 + c = 0$. Students are aware that the expression $\sqrt{n}$ specifically means the positive root of n but they fail to recognize that every positive number n would have two square roots.

Table 3: Problematic questions for the high performing perspective

Question	Type	Error Proportion	Error/Misconception
Q4	Expression	0.67	Incorrect cancellations by use of inappropriate rules in simplifying an algebraic fraction
Q16	Equation	0.60	Omitting the negative sign in front of the square root symbol - losing a solution
Q14	Expression	0.52	Incorrect simplification of a rational expression due to undistributed cancellations

Table 3 shows the problematic questions for the high performing perspective. Students' difficulties include: manipulation of algebraic fractions to the lowest form and negligence in reporting solutions in a question with more than one solution.

Figure 3: Average performer perspective

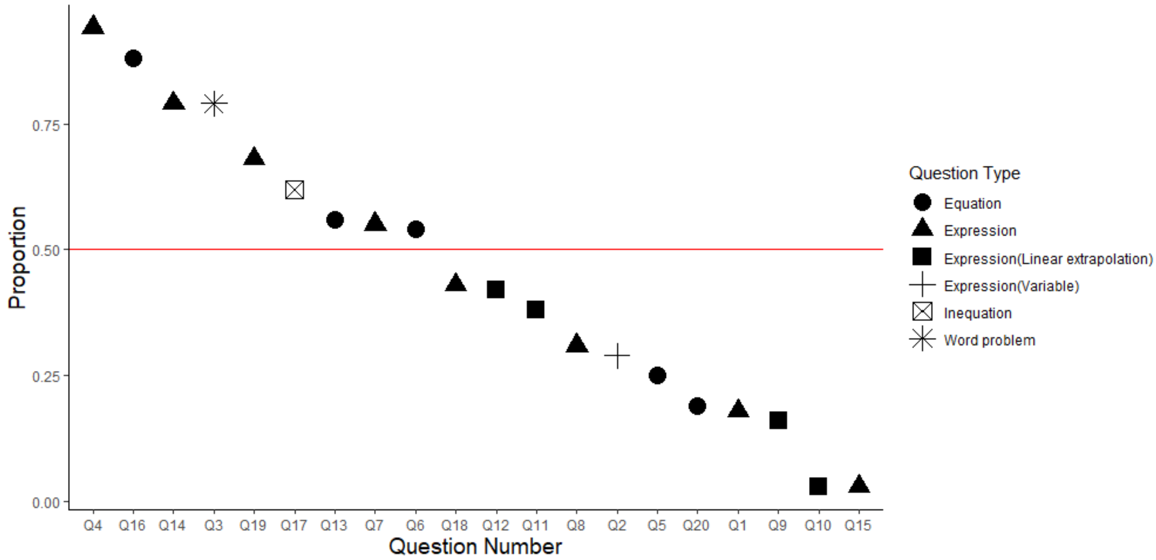

Figure 3 depicts the average performer perspective in the test. Students who performed well are those who score between six and thirteen on the test items. There is a total of sixty one individuals who qualify for which there is a mean of fifty one valid answers per question with a standard deviation of eight. Questions six and eleven have concerning deviations from this with number of valid responses being twenty six and thirty nine.This pattern mimics that of the overall trend (small deviations in the local ordering) with three additional questions termed as problematic. The most notable change concerns how the students handled the linear extrapolation questions; although not problematic but shows a division in the type showing some marked difference in difficulty between the two groups of questions being twelve and eleven compared to questions nine and ten.

Questions twelve, eleven, nine and ten are questions that reproduce linear extrapolation errors. Question twelve deals with finding square root of an expression incorporating the error that results from the misconception that $\sqrt{a+b} = \sqrt{a} + \sqrt{b}$. Also question eleven has to do with distributing the negative sign over the entire expression in the bracket of the form: $a - (b + c)$. Further, question nine involves the incorrect expansion which takes the form: $(a + b)^n = a^n + b^n$. And finally, question ten represents incorrect distribution over algebraic expressions of the form: $x(y + z)$ that might take the incorrect responses of $xy + z$ or xyz. Generally, it is observed that students performed better in questions nine and ten as compared to questions twelve and eleven. This implies that students experienced greater difficulty in manipulating square roots and distributing negatives signs when compared to expanding brackets and applying the distributive law.

Table 4: Problematic questions for the average perfomer perspective

Question	Type	Error Proportion	Error/Misconception
Q4	Expression	0.94	Incorrect cancellations by use of inappropriate rules in simplifying an algebraic fraction
Q16	Equation	0.88	Omitting the negative sign in front of the square root symbol - losing a solution
Q14	Expression	0.79	Incorrect simplification of a rational expression due to undistributed cancellations
Q3	Word problem	0.79	Error in translating a story into an appropriate algebraic equation and solving it
Q19	Expression	0.68	Incorrect numerator or denominator (LCM) when adding two algebraic fractions
Q17	Inequation	0.62	Error in manipulating a negative coefficient of a variable across an inequality sign
Q13	Equation	0.56	Misconception in generalizing over factorization when solving a quadratic equation
Q7	Expression	0.55	Misapplication of Laws of Indices - Adding powers when adding indices
Q6	Equation	0.54	Error in solving a system linear simultaneous equations with 2 unknowns - solving only for one variable only

Table 4 shows problematic questions for the average perfomer perspective in order of difficulty. These difficulties include: simplifying an algebraic fraction by using the appropriate rules; solving an equation involving the square root symbol; simplifying a rational expression by distributed cancellations; translating a word problem into an appropriate algebraic equation for solving; adding two algebraic fractions; manipulating a negative coefficient of a variable across an inequality sign; overgeneralization when solving a quadratic equation by factorization; adding powers when adding indices and solving a system of linear equations for both variables.

Figure 4: The non-response perspective

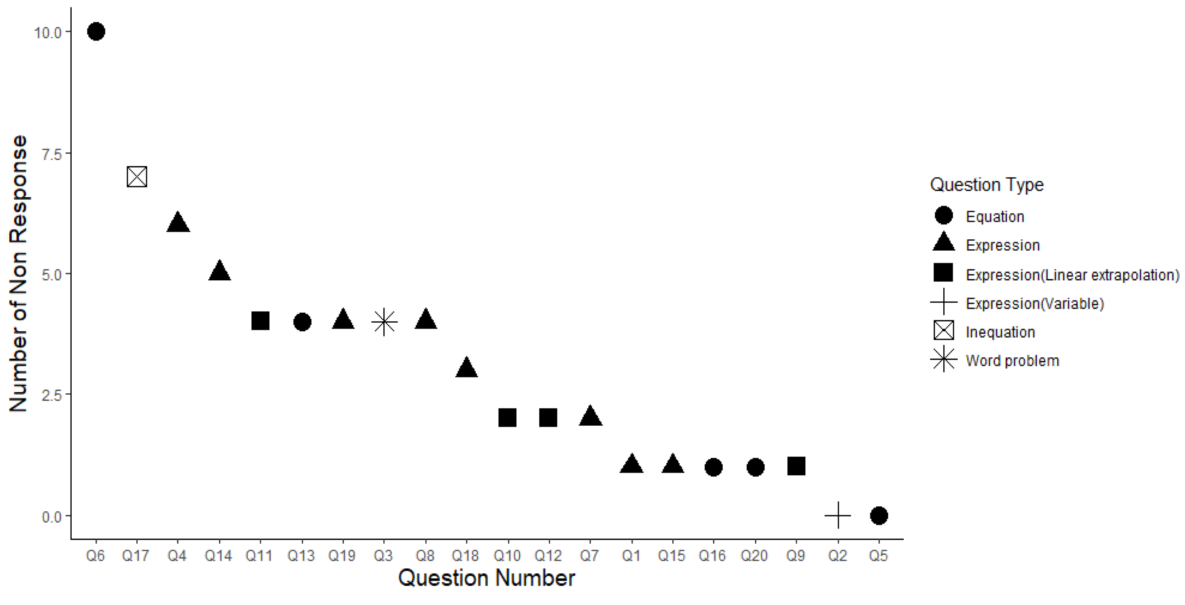

Figure 4 depicts the non-response perspective, that is those students who did not give a response to a particular question, excluding students who performed very poorly leaving a total of ninety one.

Table 5: Problematic questions for the non-response perspective

Question	Type	NR Count	Error/Misconception
Q6	Equation	10	Error in solving a system linear simultaneous equations with 2 unknowns - solving only for one variable only
Q17	Inequation	7	Error in manipulating a negative coefficient of a variable across an inequality sign
Q4	Expression	6	Incorrect cancellations by use of inappropriate rules in simplifying an algebraic fraction
Q14	Expression	5	Incorrect simplification of a rational expression due to undistributed cancellations

Table 5 shows the problematic questions for the non-response perspective in which eleven and eight percent of respondents for this group did not attempt questions six and seventeen respectively which are problematic questions for students who scored around the average but not for students who scored high. Respondents seem most unfamiliar with solving a system of simultaneous equations and an manipulating inequality.The second and third most persistent problematic questions were number four and fourteen which were both problematic for the high performers and were not the question that was avoided the most.

The effect of errors and misconceptions on students' performance

For each of the common errors and misconceptions, the difference in the mean score for students who made the error was compared using a t-test for a difference in proportions. This states that whether students making the particular error or misconception typically scored worse on the other items than students who do not make the error or misconception. A difference in four units is considered important. The sample size that is required for having a power above 0.9 with a significance level of five percent was met for all questions considered.

Table 6: Difference in the mean score for students

Question	Size of Difference	Test Type	Confidence Interval for Difference	Ordering
4	5	T-test	(3.3,6.7)	3
16	4	T-test	(2.2,5.6)	6
14	3	Mann-Whitney	(1,5.9)	7
3	3.9	Mann-Whitney	(2.9 5.9)	4
19	5.2	Mann-Whitney	(4,6.9)	2
17	2.2	Mann-Whitney	(0,3.9)	Does not meet benchmark
13	5.8	Mann-Whitney	(4.9,7)	1
7	2.8	Mann-Whitney	(2.9,6)	5
6	4.4	Mann-Whitney	(0.9,5.9)	8

Table 6 shows the difference in mean scores for the students and illustrates that all of the questions met the benchmark for an important difference between scores except for question seventeen. Questions nineteen, thirteen and four have intervals that are the furthest from zero with the lowest bound being 3.3. These questions should be considered first in making a plan for addressing errors. This is followed by questions sixteen, three and seven for which the lowest bound is 2.2. For the remaining questions although the interval does include the possible value of four, the lower bound is less than two for all of these questions suggesting that these types of questions should be addressed last as their mean scores are somewhat close to each other.

IV. Discussion

The common errors and misconceptions that students commit in MTH 1101 - Algebra at the University of Guyana, Turkeyen Campus, were investigated in this study. The analysis was conducted at four different levels, three of which differentiated the varying level of ability of the students in terms of the test scores. There was a clear trend in what errors and misconceptions were common across the levels with minor deviations in the ordering.

Students had the greatest difficulty in performing manipulation operations on algebraic fractions as well as showcasing negligence in solving for only one part of an algebraic equation solution set. A study done by Yantz (2013) on manipulations of rational algebraic expressions revealed that at least eighty six percent of the participants had difficulty in manipulating and simplifying one or more algebraic fractions correctly. Webber (1929) pointed out that when students are attempting to manipulate and simplify algebraic fractions, incorrect cancellations can occur. This is usually as a result of students' confusion of the meaning of factors and terms for which they perform incorrect cancellations by the use of inappropriate rules. Matz (1980) added that common errors in simplifying rational algebraic expressions occur as a result of the students applying a known rule to an unsuitable algebraic problem. As it relates to the algebraic equation, majority of the students in this study omitted the negative sign in front of the square root symbol and thus losing a solution when solving a quadratic equation of the form $ax^2 + c = 0$. Schechter (2009) posited that many students view the expression $\sqrt{n}$ as the nonnegative root of n, but we at the same time, we should be cognizant of the fact that every positive number n would have two square roots (one positive and one negative). This misconception is as a result of students thinking that the inverse of a square is the positive square root which may be compounded by concepts of length in measurement especially in Pythagoras' Theorem.

Other common types of errors and misconceptions in this study included: the inability to translate a word problem into its correct algebraic representation; incorrect manipulation of a negative coefficient in an inequality; incorrect manipulation of indices and negligence in reporting all the solutions to a system of simultaneous equations.

According to Mayer (1982), supported by Bishop, Filloy and Puig (2008), it is without a doubt that algebraic word problems have conventionally been the most difficult problems for some students to solve. The main issue is that students experience difficulty in translating the stories into appropriate algebraic equations and solving them. Moreover, the difficulty would manifests itself in what is referred to as a triple process: firstly assigning variable(s), secondly recognizing constants, and thirdly, which is probably the most important, representing the relationship(s) among variables and constants. Lewis (1981) added that among these processes, students have a major difficulty in translating relational aspects of the word problems into mathematical statements. In this study, majority of the students encountered difficulty in translating a word problem into its correct algebraic representation. This is supported Mulungye (2016) study which revealed that sixty three percent of the students investigated had difficulty with algebraic word problems.

More than half of the students that were investigated experienced difficulty in manipulating a negative coefficient across an inequality sign. A similar study conducted by Naseer (2015) revealed that misconceptions with inequality questions were very similar to that of misconceptions with equations. The incorrect responses are due to students applying some rules without having the fundamental understanding of how they work. Most often, students are told when a quantity is moved to the other side of the equation, the sign changes. When students try to extend this rule to inequalities, it would result in incorrect answers.

According to Rushton (2014), it is difficult for some students to simplify algebraic expressions involving indices. Common errors are manifested by students using the wrong operation for simplifying indices. In this study, more than half of the students committed error in manipulating and simplifying indices. This is supported by Ojos (2015) study which stated misconceptions in manipulating indices are connected with the misuse and overgeneralization of the laws of indices.

A study conducted by Widyastuti, Mardiyana and Saputro (2017) on students' difficulties in solving a system of linear equations revealed that majority of the participants had difficulty in using the appropriate mathematical processes towards arriving at the correct solution set which is similar to the results of this study. According to Filloy, Rojano and Puig (2008), students would experience difficulties when solving a system of linear equations for the two variables. Usually, one of the variables is represented by the letter, y, in which y would also be expressed in terms of another variable, x. In such situations, students would tend to find for one variable and omit the other, especially when they equate the two equations to solve for x.

Finally, a score comparison for the common errors and misconceptions identified showed that students who made a particular error or misconception had a score difference that included a magnitude of four; this is to say that students who made the error or misconception score worse than those who did not.

V. Conclusion

This study investigated the types of common errors and misconceptions that students committed in MTH 1101 – Algebra, their frequencies and how they negatively affect their performance. Based on the findings, it is concluded that students had the greatest difficulty in simplifying algebraic fractions and solving an algebraic equation for the complete solution set. Students also experienced major difficulty in translating an algebraic word problem into it correct algebraic representations for solving. Other significant types of errors and misconceptions included: solving an inequality that involves the manipulation of negative coefficient; solving a system of simultaneous equations to arrive at the complete solution set and manipulating indices in mixing operations of real numbers with that of exponents. The analysis also included a count on questions that students avoided; the most notable of these would be solving a system simultaneous equations, solving an inequality and simplifying algebraic fractions. The results of this study also revealed, through a score comparison test, that the errors and misconceptions students committed affected their performance negatively.

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