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# **Analysis of Students' Errors on Linear Programming at Secondary School Level: Implications for Instruction**

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## **Abstract**

*The purpose of this study was to identify secondary school students' errors on linear programming at 'O' level. It is based on the fact that students' errors inform teaching hence an essential tool for any serious mathematics teacher who intends to improve mathematics teaching. The study was guided by a descriptive survey research design. Data was collected from a purposive sample of 91 mathematics teachers from Makoni and Marondera districts who responded to a questionnaire. This was complemented by an analysis of cluster samples of 162 students' answer scripts for Question 10, in Channon et al. (2004, p. 148), followed by the application of Newman's prompts for interviews. The study found that students were unable to deduce symbolic inequalities from word problems given and confused the use of inequality signs ( $>$  and  $\geq$ ) as a result of their inability to read and follow examples in their textbook. Students also had problems with graphing inequalities and only one student managed to deduce the profit function. The study noted that errors were arising from students' low proficiency in mathematical language as reflected by the highest errors at the reading level and wordy problems which students did not understand. Textbook examples were also structured for the bright student and teachers not properly sequencing their concepts. It was also noted that pupils with no graph papers had limited teachers' practice exercise assigned. The study recommends the following instructional strategies for teachers: structuring introductory exercises; teach students to read mathematics textbook examples and learn from them; and encourage students to read inequality statements as complete sentences.*

## **Introduction**

Students' error analysis in mathematics is an important activity for any serious mathematics teacher as a basis for informative evaluation. Error

analysis can be done during lesson delivery, oral discussions, when marking students' answers to exercises and in-class tests. Teachers can use students' errors to reflect on their teaching methods, textbooks used and the needs of the students. In fact, known and predicted errors on specific topics like linear programming help teachers speculate questions and answers during lesson planning. In this study error analysis provides a basis for student targeted instruction to correct errors on linear programming.

This study accepts that mathematics learners, be they primary, secondary school or adults at university level, make errors against the expectations of their teachers. According to Legutho (2007) students' errors in mathematics are inevitable; they arise from mathematics as a subject, textbooks used or are results of teaching. Russell (2001) justifies mistakes as a learning ingredient when he/she notes that the most powerful learning experiences results from making mistakes. Booker (1989) pointed at the teacher as a source of students' errors because "the origins of many errors are rooted not so much in students but in the manner children are introduced to mathematics" (p.101). It is hoped that when students' errors are used for instruction, students can pass their 'O' level mathematics. Teachers being a contributing variable are encouraged to carry out error analysis as part of their teaching introspection.

Chinamasa (2008) emphasised that passing mathematics at 'O' Level is an important achievement in Zimbabwe and the world over. A passing grade C or better is a requirement for all 'A' level sciences, commercial and practical subjects like building and agriculture. Mathematics is also an essential requirement for primary school teacher training and a general requirement for most degrees except for the languages. Kuneka and Chinamasa (2012) found that 'O' level mathematics was also necessary for nursing although student nurse recruitment adverts are currently silent on it. Johnson and Johnson (1994:168) summarised the need for mathematics when they said, 'Lack of numeracy was related to unemployment and low income among adults.' Haury and Milbourne (1999) concluded by suggesting that, limited mathematics proficiency leads to limited success in handling society's daily challenges. These sentiments lead to the conclusion that, adults without mathematical skills are disadvantaged somehow in today's life where technology based on figures demand application.

The need for 'O' level applied mathematics call for efforts to be directed towards students' understanding of topics such as linear programming and the graphical methods. Linear programming is one of the optional topics on the Zimbabwe Schools Examinations Council (ZIMSEC) 'O' Level Mathematics Paper 4008/2. The question carries a total of 12 marks. According to Lucy (1992), linear programming is “a mathematical technique concerned with the allocation of scarce resources. It is a procedure to optimize the value of some objective function when the factors involved are subject to some constraints.” (p. 238). The word procedures imply the application of series of steps in their correct order. The procedure may call for the use of procedural instruction like the lecture method.

An analysis of the Zimbabwe Schools Examinations Council (ZIMSEC), 'O' Level Mathematics Syllabus (4008/4028) reveals that linear programming is taught to enable pupils to:

- i) acquire a firm mathematical foundation for further studies and/or vocational training
- ii) develop the ability to apply mathematics in other subjects
- iii) develop the ability to reason and present arguments logically
- iv) develop the ability to apply mathematical knowledge and techniques in a wide variety of situations, both familiar and unfamiliar

The word “ability” in three of the aims implies that teaching and learning of linear programming should be activity based involving real life problems. It also calls for the need to apply mathematics in other subjects for an interdisciplinary approach or use of projects during teaching.

These syllabus aims show that linear programming is an applied concept in which teachers should use real life problems and examples. Gharibhi (2007) advised teachers to draw examples from the following:

- 1) production and operations management quantifying the production costs and profits  
Mathematics can be linked to agriculture or building.
- 2) finance regarding investor portfolio and mixed variable

- selection
- 3) human resources management, focusing on personnel deployment planning
  - 4) advertising to determine optimum media mix to portray the most effective capturing
  - 5) scheduling of various activities to determine the optimal schedule and project completion

Unfortunately the bulk of teachers have no experience from industry. This makes it difficult for the teacher to understand the context of the problem: let alone formulating a contextualised problem.

According to syllabus (4008/4028) during the examination; students will be assessed on their ability to:

- i) carry out algebraic calculations and geometric manipulations accurately
- ii) draw graphs, diagrams and constructions to given appropriate specifications
- iii) translate mathematical information from one form into another, for example from a verbal to symbolic or diagrammatic form
- iv) apply and interpret mathematics in daily life situations

These assessment objectives reveal that linear programming requires application of a cumulative set of mathematical skills and concepts. This aspect requires teachers to review assumed knowledge first. In fact, Kufakowadya and Nyamakura (2010) hinted that although inequalities and the number line are done at Form 2 level, it is useful to do a recap of these topics to enhance the understanding of linear programming.

### **Statement of the research problem**

Pupils in Makoni and Marondera districts are facing difficulties in understanding linear programming at “O” level. They ranked it the second most difficult topic after transformation. Their misunderstandings are shown by their inability to use inequality signs in appropriate situations. Given a choice, students would not attempt the linear programming question.

## **Study objectives**

The research problem motivated researchers to:

- 1) identify errors committed by pupils on linear programming
- 2) deduce factors contributing to these errors
- 3) suggest teaching strategies to reduce pupils' errors and improve their performance on linear programming

## **Significance of study**

This study sought ways of improving the teaching of linear programming at 'O' level. It is important in that the majority of studies in mathematics education have provided a bird's eye view of teaching and learning and not a detailed analysis of a topic like linear programming. This study, then, provides feedback to curriculum designers and textbook writers on linear programming. Teachers will find it a useful source for their instructional methods for the dreaded topic on linear programming.

## **Literature review**

### **Mathematics as a discipline**

According to Atherton (2003), in the teaching and learning interaction between the teacher, the learner and the subject being taught, the subject is not neutral. Mathematics specifically imposes its own language and logic which contributes to students' errors. Johnson and Rising (1972:3) regarded mathematics as a way of thinking which encompasses arithmetic (science of numbers and computation), algebra (the language of symbols and relations), geometry (a study of shapes, size and space), statistics (science of interpreting data and graphs) and calculus (a study of change, infinity and limits). From an applied angle, Howson (1988) considered mathematics as a study of patterns (any regularity in form or idea such as sequences). It is a language which adds precision to communication using ideograms (symbols for ideas such as  $x \leq 4$ ), to facilitate mathematical communication and computation.

The application of graphical method for linear programming is based on these assumptions from Render, Stair and Hanna (2012, p. 271).

- 1) Problems seek to maximise or minimise an objective.
- 2) Constraints limit the degree to which the objective can be obtained.
- 3) There are alternative courses of action available.

- 4) Mathematical relationships between variables are linear in divisible proportions.
- 5) The number in the objective and constraints are known with certainty and remain constant during the study.
- 6) Solutions need not be restricted to whole numbers (integers), they are divisible and may take fractional values.
- 7) Negative values of physical quantities are impossible; hence all answers or variables are nonnegative ( $x \leq 0$  and  $y \geq 0$ ).
- 8) Graphical method works only when there are two decision variables to facilitate use of a two dimension Cartesian plane.

A student makes an error when one or more of these assumptions are violated in the process of solving a problem by linear programming. Identification of such errors helps teachers note assumptions to be stressed during instruction.

### **Students' errors in mathematics**

Most students' mistakes are not due to uncertainty or carelessness; rather students' errors are the result or product of previous experiences in the mathematics classroom. Radatz (1980) argues that students' errors in mathematics education are not simply a result of ignorance, stupidity and situational accidents. In this study students' errors are systematic deviations from acceptable mathematical computation and graphing procedures. This perception encourages teachers to analyse students' errors from the classroom in which they were formed.

According to Frank (2009) assumptions behind teachers studying learners' mathematical errors are that:

- 1) Errors are an indicator of the difficulties encountered in learning the target concepts.
- 2) Errors enable teachers to predict likely errors for a group of learners and provide remedial teaching.
- 3) Errors point to the possible strategies used by students to learn the concepts.
- 4) They are a source of understanding learners' development stages.

These sentiments emphasise the significance of the current study on students' errors on linear programming.

Factors accounting for pupils' performance in mathematics were



examined from different perspectives the world over. Studies of British pupils carried out by Little (cited by Mushoriwa, 2003) highlighted the significance of the teacher and the school context as a whole. The studies did not examine the instructional strategies which make the teacher effective and did not suggest ideal contextual environments. In another study, Holt (1978) suggested psychological factors in pupils such as high levels of anxiety stimulated by fear of failing mathematics and disappointing their equally anxious significant others, for example, parents and boy/girl friend. He also pointed that, pupils are confused by the mathematics content that is not linked to their everyday lives. Barrassi (1997) concurred and advised teachers to use real life situations such as maximising consumer satisfaction or utility when teaching linear programming.

Focusing specifically on Africa, Macforlone (1990) argued that, mathematics conceptual development for African learners is affected by a lack of a curricular and teaching material specifically designed for Africa. One can accept the view from the observation that, mathematics textbooks and instruction lack local conceptualization. This is exemplified by African teachers using English as a medium of instruction to teach African learners.

From Malawi, Ntata (1999) found out that some Form 3 pupils exhibit negative attitudes and lack confidence in mathematics. One is bound to buy into Ntata's findings due to the fact that Zimbabwe and Malawi have a lot in common. Specifically they were all colonies of Britain and inherited a British academic education system with cosmetic changes. In Zimbabwe, Machinga (2000) attributed poor 'O' level pupils' performance in mathematics to large class sizes as ripple effect of the massified educational expansion of the post-colonial era. From Nyagura and Jaji (1989), the study gathers that teachers in both primary and secondary schools are important factors in pupils' mathematics learning process. What is clear is that these are general surveys which do not show how teachers influence pupils' understanding or errors in linear programming.

According to Jaji (1992) the medium of instruction, English is an inhibiting factor. She established that Form 2 pupils in Zimbabwe lack mathematics reading skills and language. This is a critical factor for

linear programming problems which are presented in word forms. Nziramasanga's (1999) report concurs with Jaji and suggested that teachers should use the mother language to develop pupils' mathematical concepts. The setback in this case is assumed to be the language used by teachers to develop understanding of linear programming.

Researchers have taken different angles for projecting their studies on error analysis in mathematics. Russel (2001) noted that primary school children committed the following:

- i) mechanical errors arising from hurried approaches and forgotten steps
- ii) application errors showing students' misunderstanding of one or more steps
- iii) knowledge gaps reflecting lack of concepts and unfamiliarity with terminology, and
- iv) incorrect operation order stemming from rote learning

Cohen and Spencer (2007) focused on word problems and found that students:

- 1) had difficulty with reading mathematics word problems
- 2) showed inability to relate context of the problem to real life situation
- 3) failed to distinguish relevant from irrelevant information
- 4) were unable to identify the number of steps required to solve the problem
- 5) had trouble with mathematical operations of directed numbers

However, these findings cannot account for 'O' level students' errors in linear programming.

Booker (1989), who was interested in error analysis for targeted instruction, analysed students' answer scripts which revealed that errors originated from:

- 1) incoherent structure of presenting mathematics content
- 2) use of inappropriate textbook examples for concept formation
- 3) unsuitable exercise problems emphasising drill of procedure with no rationale for evaluating the process and answer
- 4) underestimating the necessity for basics by teaching new content before assumed knowledge is verified
- 5) inappropriate response to students' errors

- 6) class work based on the work of selected students asked to work on the board while the rest copy the solution

All these sources are variables which can be controlled by the teacher hence the need for this study to find solutions applicable by the teacher. A more comprehensive method of analyzing students' errors suggested by Newman (1977) involve asking a student five prompts to determine the students' levels of errors. The prompts are:

- 1) Read the question to me. If you don't know a word, leave it out. (Reading).
- 2) Tell me what the question is asking you to do. (Comprehension).
- 3) Tell me how you are going to find the answer. (Transforming)
- 4) Tell me what you do to get the answer. Speak aloud as you do to get the answer. Speak aloud as you do it so that I can understand how you are thinking. (Procedure or Skill)
- 5) Write your answer to the question. (Encoding in symbols or words).

Clements (1980) used Newman's prompts to analyse 726 grade 5 to 7 pupils' errors in Papua New Guinea and found that 50% of the errors first occurred at the reading, comprehension and transformation levels. Clements concluded that teacher remedial activities which focus on procedural method are misdirected. Lankford (1994) extended the application of Newman's error analysis to adult learners and found that nurses had errors at the comprehension and transformation level. What is not yet clear is the type and level of errors 'O' level students make in linear programming. This study extends the application of Newman's (1977) error analysis prompts to 'O' level students learning linear programming.

## **Methodology**

### **Research Design**

This study is guided by a qualitative descriptive survey. It is justified by Kothari (2004) who noted that descriptive research includes surveys and fact finding enquiries of different kinds. According to Mustafa (2010), the major purpose of descriptive survey is to describe the state of affairs as it exists. The researcher does not manipulate variables. In this study the descriptive survey facilitated the description of students' errors in linear programming.

Another strength is that descriptive surveys apply different methods of data collection to enhance method and data source triangulation. In this study it enabled the administration of a teacher's questionnaire, script and textbook question analysis and application of Newman's (1977) interview prompts to collect data.

### **Population and sampling**

Data for this study was collected from 'O' level pupils who had done linear programming and 'O' level mathematics teachers in Makoni and Marondera district. Mathematics schemes of work and the main 'O' level textbook Channon et al. (2004) being used contributed to the data. Purposive sampling was used to get 91 mathematics teachers who attended a mathematics association meeting in Rusape and Marondera. These also brought their 'O' level mathematics scheme books. Since the total number of 'O' level students is known, this is a finite population hence probability sampling was appropriate. Each school's uniqueness was expected to influence pupils' errors in linear programming hence each school was considered a unique cluster. Cluster sampling was applied to select 162 students from 13 secondary schools. There was proportional sampling from school to school to cater for the qualitative variation then simple random sampling of Form 4 pupils per school. Students' examination registration numbers were matched with computer generated random numbers to select the 162 student participants.

### **Instruments**

Students' errors were analysed from 'O' level students' answer scripts to Question 10, Exercise 17b in Channon et al. (2004, p. 148), New General Mathematics Book 4. Teachers responded to a questionnaire which sought students' errors on linear programming, possible sources and targeted instruction.

Teachers' scheme books were analysed for teaching methods used; sources of exercise problems and sequencing of concepts and topics. During the lesson, Newman's (1977) error analysis interview technique was used as 'O' level pupils answered Question 10, Exercise 17b. The instruments used in this study are: a teacher questionnaire, scheme books, students answer scripts and Newman's (1977) prompts

questions to improve validity and reliability of findings.

### **Data collection**

Data collection was initiated by mathematics teachers at a workshop identifying linear programming as a topic in which students had difficulties. This was followed by teachers completing the questionnaire at their schools. Two weeks was given to allow time for them to think about their students' errors and how they could be dealt with. The researcher visited each of the 13 secondary schools in the district to administer Question 10, Exercise 17b. Students were informed that the test was an error diagnostic instrument. Its findings were to be used as a basis for their revision error targeted teacher instruction. The researchers invigilated and marked the test scripts. During marking, errors were recorded and error frequency tables generated. Errors were also indicated on the students' script for them to benefit from the study.

Teachers submitted their schemes for analysis. Two weeks later workshops on error analysis were held in Rusape and Marondera. Students' errors in the scripts were discussed by teachers. Remedial instructions were suggested. The researchers returned marked scripts to each school and carried out one-on-one interviews with 73 students who had failed. These were considered rich sources of errors. The researchers used Newman's (1977) prompts to classify students' errors on linear programming.

### **Findings**

Students answer script analysis and responses from teachers revealed that students make the following errors when answering questions on linear programming by graphical method:

**Table 1**

*Students' Errors on Linear Programming*

*N = 162*

Type of Errors	Frequency
<p>a) Inequality formulation from word problem</p> <p>(i) Confusion over the use of inclusive and strict inequality, for example, <math>x + y &lt; 1000</math> instead of <math>x + y \leq 1000</math></p> <p>(ii) <math>x + y \leq 2</math> for the brands</p> <p>(iii) <math>x &gt; 100</math> instead of <math>x \geq 100</math></p> <p>(iv) <math>2y &gt; x</math> instead <math>y \geq 2x</math></p>	<p>113</p> <p>70</p> <p>140</p> <p>94</p>
<p>b) Graphical / programming</p> <ol style="list-style-type: none"> <li>1. <math>x, y</math> axis reversed</li> <li>2. Inability to use scale</li> <li>3. Confusion over use of letters <math>x</math> and <math>k</math> for Kula and <math>y</math> and <math>s</math> for Sundown</li> <li>4. Inability to draw lines on Cartesian plane in particular their <math>2y &gt; x</math> or <math>y &gt; 2x</math></li> <li>5. Drawing short boundary lines which do not intersect <math>y &gt; 2x</math> starting at (0;0) and ending at (300;600) before intersecting <math>x + y &lt; 1000</math></li> <li>6. Inability to locate the origin (0;0) on graph</li> <li>7. Difficulties in determining wanted from unwanted region particularly for <math>y &gt; 2x</math> and <math>x + y &lt; 1000</math></li> </ol>	<p>84</p> <p>87</p> <p>120</p> <p>80</p> <p>119</p> <p>90</p> <p>150</p>
<p>c) inability to form the profit function: <math>p = 3x + 2y</math></p>	<p>155</p>
<p>d) Inability to identify points within the wanted region (affected by use of scale)</p>	<p>100</p>
<p>e) Substitution, particularly <math>3c = \\$0,03</math> and <math>2c = \\$0,02</math> to get</p>	<p>161</p>

## Discussion

Researchers asked students “why” they had  $x + y \leq 1000$ . Their answers indicated that the words, in Channon et al. (2005, p. 148) Question 10 “has room for up to 1000 cans” meant that the shopkeeper could stock 1000 cans hence  $x + y \leq 1000$  which contradicts the answer given  $x + y < 1000$  in the textbook. Students’ answers were correct but marked wrong by teachers because they were different from that given in the Teacher’s Book. Teachers are encouraged to structure marking guide for each question they assign instead of relying on the Teacher’s Book.

Some students pointed out that they were guided by example 5 in Channon et al. (2005, p. 146). Part of the example reads, “... a business needs at least 5 buses and 10 minibuses.” The inequalities were  $x \geq 5$  and  $y \geq 10$ . The word “at least” was associated with or equal to, hence in this question “at least twice as many cans of Sundown as Kula” implied,  $y > 2x$  and  $x \geq 100$  instead of  $y > 2x$  and  $x > 100$  textbook answers respectively. Students’ who followed textbook examples, got the correct answers different from that given in the answer book and teachers marked their answers wrong because, again, they were different from those in the Teacher’s Book.

From these findings the researchers concluded that students' errors are arising from three sources:

- 1) low proficiency in contextualised English mathematical language
- 2) textbook examples structured for the average and bright students
- 3) students' inability to read and follow textbook examples
- 4) teachers who do not prepare marking schemes for questions relying on answers in the Teacher’s Book

Teachers pointed out that linear programming problems are too wordy for “O” level students struggling with English as a second Language. This specific problem has 196 words which teachers perceived as being good for comprehension rather than mathematics application.

Errors on graphing, originates from students' low understanding of the Cartesian plane. Teachers' schemes did not link the straight line graph with linear programming. Limited assumed knowledge was verified

before teaching linear programming. Teachers attributed this to the limited time of one week allocated to linear programming. In this case, the majority of teachers violated the advice by Haury and Milbourne (1999) to teach mathematics as a coherent whole by correct sequencing of content concepts to show the interconnections among different topics.

Table 2  
*Newman's Error Analysis Categories N = 73*

Type of Error	Frequency
Reading	57
Comprehension	40
Transforming	30
Process or Skill (application)	25
Encoding (presentation)	45

Findings show that students' errors are highest at the initial reading stage. They decrease to the process or skills application then increase again at the encoding. We accounted for this trend by noting that, the question used was too wordy, 196 words. Teachers' scheme books revealed that the main teaching method was lecture and demonstration which emphasised process and skills development hence least errors for the process as a result of procedural teaching methods used.



Table 3  
*Factors Contributing to Students' Errors*

*N = 93*

Factor	Rank frequency
1. Low comprehension of English Language	1
2. Teachers not verifying pre-requisite concepts	2
3. Teachers not linking concepts applied in linear programming	3
4. Pupils limited assumed knowledge	4
5. The concept cumulative nature of the topic linear programming	5
6. Textbooks limited illustrative examples and use of foreign industry problem examples	6
7. Teachers being too fast for the slow and average pupil in class	7
8. Teaching methods limited to lecture and demonstration	8
9. Pupils with no graph paper to use for practice	9
10. Classes too large for the teacher to offer individual help	10
11. Shortage of time, one week, for linear programming	11

Findings in this table show that 'O' level students' errors on linear programming are influenced by:

- 1) the nature of the subject content
- 2) the English medium of instruction
- 3) the teachers method of presentation, and
- 4) resources like graph books

### **Implications for instruction**

This study suggests that teachers can reduce 'O' level students' errors on linear programming by implementing these:

- 1) Schools factor the cost of graph-books on fees.  
 Buy graph-books in bulk and issue a graph-book to each child registering for mathematics at 'O'-Level.
- 2) Structure introductory exercises which review the following concepts:
  - a) language used for linear programming such as less than ( $>$ ), less or equal to ( $\leq$ ),

- a) Solution of inequalities by calculation
  - b) The number line graphs for  $x > a$  and  $x \geq a$
  - a) Cartesian plane emphasising the (0: Y) and (X:0) points
  - b) Programming on the Cartesian plane starting with horizontal ( $y < a$ ,  $y \geq b$ ), vertical ( $x > a$ ,  $x \leq b$ ) then a linear combination of  $x + y < b$ .
- 3) Recap pre-requisite concepts using structured exercises.
  - 4) Allocate at least 2 weeks for linear programming.
  - 5) Help students to read mathematics textbooks, see underlying structures and learn from provided examples. This is a skill teachers must develop in their pupils.
  - 6) Use real life examples from students' environment and experiences' environment and experiences. Ask students to deduce the objective functions and constraints.
  - 7) Train students to apply more than one method to solve a problem. In this case students can apply simultaneous equation to determine corner point coordinates.
  - 8) Provide more problems for students to practice solving and marking. This study found that the average number of linear programming problems done by pupils was three. We recommend at least seven problems.
  - 1) Teachers are encouraged to learn how to use computer spread sheets for linear programming.
  - 10) Use of the project method done by students in groups is called for to promote pupil-to-pupil teaching and learning.

## Conclusion

This study sought to identify students' errors on linear programming at 'O' level. It was motivated by the fact that students' errors reveal students line of thinking, problem analysis strategy and problem conception. From this angle then, error analysis informs teaching and is an essential tool for mathematics remedial teaching. The study found that students made errors in the deduction of symbolic inequalities from word problems. They also showed errors in comprehension and application of techniques illustrated by worked examples in their textbooks. From the findings, the study concluded that the medium of

instruction, English, contributed to errors made by students who used English as a second language. The business context, which was used in the problem, also contributed to students' errors in the deduction of the profit function that was required in this problem. Lack of resources such as graph paper limited students' practice in solving linear inequality problems. Teachers are encouraged to implement the suggested strategies to improve pupils' performance in linear programming at 'O' level.

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