Learners' conceptual resources for learning kinematics graphs

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Abstract. Learners' difficulty in the application of basic graphs concepts to solve kinematics graphs problems contributes to underperformance in physical sciences. Their ability to handle problems in kinematics graphs could be enhanced if they have effective conceptual resources on graphs. In South Africa, this underperformance could be due to a gap between the GET [General Education and Training] and FET [Further Education and Training] band's requirements on graphs. For this reason this study selected to investigate the conceptual resources acquired by grade 10 learners from grade 9 that can be used productively for the learning of kinematics graphs in grade 10. The use of mixed method approach was considered appropriate for this study. The mixed method depended on a quantitative method (questionnaire) to produce precise and measurable data, while a qualitative method (interviews) was to enhance the understanding of the data produced by the quantitative method. Patterns and trends in learners' knowledge and reasoning were probed. The results showed that many learners could answer mathematics questions but struggled with similar questions in kinematics. From the results it can be deduced that learners' conceptual resources can influence their understanding of kinematics graphs in physics. These resources are gained from previous learning in mathematics and natural sciences.

1. Introduction

Graphs can be found in many of the natural sciences and physical sciences textbooks used in South African schools.It is therefore apparent that learners have opportunities to develop graphical skills that include amongst others interpretation of data, drawing of graphs and tables, reading from graphs and interpretation of graphs. These skills are important for understanding sciences and analysis of data for research purposes and should be understood especially by learners who wish to continue with formal education.

Graphical skills are also essential for everyday life activities since they are commonly found in reports, periodicals and journals. In South Africa, grade 9 is the first exit level that serves as a gateway to the world. Learners can end their formal education at the end of grade 9 and they should be able to use the knowledge gained at this level to fend for themselves.

The research question is: What conceptual resources have Grade 10 physical sciences learners obtained in the GET band that can be productively used for the learning of kinematics graphs in the FET band?

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1.1. Components of graph in the National Curriculum Statement for grade 10 to grade 12
Graphs are an inherent component of the natural sciences and physical sciences curricula in South Africa. The National Curriculum Statement (NCS) for physical sciences from grades 10 to 12 considers graphs as an important process skill that contributes to the construction and applications of science knowledge [1]. For example, grade 10 learners are expected to seek patterns and trends in data and represent them in different forms, including graphs.

1.2. Importance of graphs
Many teachers consider the use of graphs in the laboratory as important for developing understanding of topics in physics [2]. The ability to use graphs correctly is an important gate way to produce expertise in problem solving in science [3]. Reflecting on the importance of graphs [4] are quoted as follows, ''Line graph construction and interpretation are very important'' becausethey are ''an integral part of experimentation, the heart of science'' [5]. On the contrary, 38.3% of the learners that participated in the study agreed that graphs are important.

1.3. Difficulties learners experience in graphs
According to [3] learners' difficulty in application of basic concepts in graphs to solve problems leads to difficulty in understanding concepts such as the gradient of kinematics graphs. Their learning problems are enhanced if they do not have an effective knowledge base (or resources) on graphs. Most learners find graphs, especially line graphs, difficult to draw and interpret [6]. In a study of South African physical sciences learners' mathematics procedural and conceptual knowledge, [7] found that the section on interpretation and application of graphs had the lowest overall performance. This can be attributed to the fact that the comprehension of kinematics graphs is influenced by learners' prior knowledge and familiarity of graph concepts.

1.4 Learning
Learning is defined as an act of gaining knowledge [8]. From the constructivist perspective, learning involves activities that lead to learners constructing their own theories, by building on their prior knowledge [9], [10]. Learners relate well to learning when they are given the opportunity to construct their own theories and ideas through constructive scientific activities guided by their prior knowledge. That means activities developed from learners' existing knowledge can lead to effective learning.

2. Design and method
A mixed method was used where qualitative and quantitative research strategies were combined and applied in the investigation. A questionnaire was used to quantitatively determine the occurrence, and determine correlations between mathematics and science questions that deal with the same aspect (e.g. gradient understanding and use of scale to draw graphs), amongst 201 grade 10 learners from 7 local schools. The questionnaire used was compiled by the researchers. It contained relevant questions from existing research questionnaires [1],[11], South African Grade 9 and 10 textbooks and examination papers. The validity and reliability of the questionnaire was ensured by content review by researchers in the field, a pilot study and statistical calculation of Cronbach Alpha values. The descriptive statistics that were used to describe the data were the frequency distribution and mean of the data.

The questionnaire was followed by interviewing three grade 10 learners to determine the conceptual resources and understanding thereof, which was qualitatively analysed. The learner with the highest mark, lowest mark and one average were randomly selected. The varying abilities of the extremes give a wider range of coverage of learners' conceptual resources and understanding.

The mixed method (QUAN-qual) used is summarized in the diagram below:

QUANTITATIVE	→	**Qualitative**
Data collection and analysis of results	**Followed-up**	Data collection and analysis of results

Figure 1. QUAN-qual mixed method used

3. Results of empirical study

3.1 Questionnaire results

The Cronbach's alpha coefficient of the questionnaire was above 0.7 after deletion of some items, which denotes consistency, reliability and validity of the questions used. These questions can therefore be understood in the same way by different populations.

Table 1 shows the learners' responses to the group of basic concepts items from the questionnaire.

Table 1. Learners' response to basic concepts questions

Grouping-Criteria	Description	Frequency (N=201)	Percentage %
	Distance	48	23.9
Basic concepts	Speed	22	10.9
	Unit for speed	46	22.9
	Unit for distance	90	44.8
	dependent variable	57	28.4
	independent variable	60	29.9
	Constant variable	23	11.4

The constant variable was correctly identified in the given problem situation by 23(11.4%) of the learners (table 1), while 57(28.4%) could identify the dependent variable and 60(29.9%) the independent variable. This result can probably be attributed to the lesser degree of application of these terms in grade 9 mathematics and natural sciences. The concepts of *distance* and *speed* were explained using everyday applications. For example, definitions such as "how far things are away from each other'' and ''how far you travelled'' for distance. ''How fast or slow an object moves'' for speed was provided as response. Only 48(23.9 %) and 22(10.9%) of the learners were able to give scientifically acceptable descriptions of distance and speed respectively. The questions on units of measurement were answered much better than the definitions. The unit for speed was given correctly by 46(22.9%) of the learners while 90(44.8%) learners could provide the unit of distance.

The basic concepts needed to learn kinematics graphs seem to be lacking among the learners who participated in the study. A total average percentage of 23.9% responded positively by providing the expected answers to the questions.

Table 2 below shows the learners' responses to graph-related questions from the questionnaire.

Table 2. Learners' responses to graph-related questions from the questionnaire

Grouping-Criteria	Description	Frequency(N=201)	Percentage %
Graphs	Interpreting graphs	44	21.9
	Draw bar graph using correct label & scale.	53	26.4
	Draw line graph using correct label & scale.	44	21.9
	Use of scale	39	19.4
	Draw distance/time graph	32	15.9

A small number 44(21.9%) correctly interpreted the given graphs. The number 53(26.4%) of the respondents demonstrated acceptable skill of drawing bar graphs, however 44(21.9%) demonstrated all the skills of drawing line graphs, labelling axis, plotting points and using scale correctly. The use of scale was poorly answered, 39(19.4%) of learners from all the schools that participated in the study were able to draw the axis to scale. A total of 32(15.9%) learners demonstrated the skill of drawing a distance/time graph from the given data.Drawing of line graphs appeared to be challenge for the learners.

Table 3. The mean score of the various groupings

Groupings-Criteria	Number of participants	Mean
Basic concepts	201	24.60
Graph interpretation–Mathematics	201	39.89
Graph interpretation-Physics	201	34.92
Gradient – Physics	201	40.73
Gradient – Mathematics	201	60.30

Table 3 refers to the mean score illustrating learners' performance. The learners performed better in gradient -mathematics than gradient physics with a mean score of 60.30 and 40.73 respectively than in graph interpretation-mathematics with a mean score of 39.89. The answers of graph interpretation-mathematics showed a large variability. A mean value of 39.89, for graph interpretation-mathematics, shows that there was a wide variety of responses to the interpretation of the graphs-related questions.

For given intervals learners were asked to state whether the gradient is positive, negative, or zero and over 45% were able to provide the accepted answer for each interval for the physics questions. However over 70% of the learners were able to interpret the given mathematics graphs correctly. It is perhaps due to the lack of exposure to such questions in grade 9 that contributed to fewer learners' 99(49.3%) ability to identify zero gradients.

3.2Interview results
All the interviewees agreed that they were taught how to calculate the gradient from a given formula and to determine the gradient from graphs in grade 9 mathematics. That was why they were able to attempt the gradient related problems. This implies that if emphasis is placed on transfer and integration of graph skills from mathematics to physics by the grade 9 mathematics teachers, the gap between grade 9 and grade 10could be narrowed. The interviewees confirmed that there is currently a huge gap between grade 9 natural sciences and grade 10 physical sciences.

4. Analysis and Discussions

4.1 Conceptual resources

The knowledge and skills obtained in graphs as learners proceed from grade 8 to grade 9 will be built upon in grade 10. The concepts and terms related to graphs that were acquired in grade 9 should serve as conceptual resources in learning kinematics graphs in grade 10.

4.1.1. Basic concepts: The findings revealed that the learners had difficulties with the basic kinematics concepts, for instance only 15.9% of the participants could draw the graph (distance/time) from given data. On the average, 33.2% could distinguish between speed and distance. The difficulty in differentiating between related concepts such as distance and speed remains a challenge.Molefe stated that one of the most common and a critical problem in physics education is the failure to differentiate between various kinematical quantities [12]. This was found to be true for this study. For example, only 26.4% and 22.9% of the respondents could write the correct unit for speed and distance respectively. They used everyday life descriptions for speed and distance instead of giving the scientific definitions.

4.1.2. Drawing and interpretation of graph: [2] found that most of the graphs in his study were not drawn to scale. Very few (19.4%) participants could draw the x and y axis to scale. This can be attributed to inadequate practice in grade 9. Interpretation of graphs can be a resource for learning kinematics graphs if the skills are properly mastered and correctly applied in grade 9. The educator should also ensure that the learners transfer their resources to new contexts such as kinematics graphs. If learners can interpret graphs and calculate the gradients then they have the needed resources to interpret and solve kinematics graphs problems.
The analysis of the quantitative and interview data indicate a lower percentage of learners' ability to interpret the kinematics graphs and this is in line with Beichner results where only 39% of the participants were able to provide the correct description for given kinematics graphs [1].

4.1.3. Gradient: The conceptual resource, gradient of graphs, was taught in grade 9 mathematics. The calculation of gradient, determination of gradient from a graph and drawing a graph are resources related to kinematics graphs that learners should have acquired in grade 9. These concepts are appropriately included in the grade 9 mathematics textbooks used by the participants of this study [14]. Calculation of gradient should have been taught intensively in grade 9 mathematics classes. This seems to be reflected in the results of the quantitative analysis, according to which more than 70% of the learners were able to distinguish between positive and negative gradients. The learners did not use the same concept in solving similar problems on gradients in physics. However, the interview results indicated that they do not have a good understanding of the concept of gradient. The reasoning given by the learners was not scientifically correct, e.g. "the line is longer therefore it's a positive gradient". With reference to the question asked they should have referred to the definition of gradient in terms of the ratio of changes in displacement and time or ($\Delta y/\Delta x$). Learners explained positive gradients as increase in gradient but did not apply their concept scientifically to solve problems related to gradient.

Analysis of the results revealed that learners struggled the most in the items concerning the following:

- Understanding and identifying variables.
- Identification of zero gradients.
- Interpretation of the point of intersection of line graphs.
- Differentiation between position and speed.
- Interpretation of kinematics graphs.
- Scaling.

5. Summary and discussion of findings
Based on the arguments from paragraph 1.4 on learning, one can deduce that having pre-knowledge about a topic, or possessing conceptual resources should contribute towards effective learning. Therefore the poor performance in kinematics graphs can be attributed to the fact that learners do not have all the necessary conceptual resources to learn kinematics graphs in the FET phase which include physics concepts and mathematics skills.

Conceptual resources
The conceptual resources that the grade 10 participants have for effective learning of kinematics graphs as obtained from the analysis of the results of the study are:

- Gradient: Calculating gradient.
- Deducing information from a graph: Identifying positive and negative slopes.
- Identifying trends: Decrease, increase, remains the same.
- Drawing graph: Plotting points. Table to graph conversion.
- Units: The units of basic kinematics physical quantities.

6. Conclusion

In conclusion the grade 10 learners who participated in the study do not have adequate conceptual resources (prior knowledge) to solve kinematics graph problems. Their resources are not coherent, i.e. learners do not apply knowledge consistently in different problems.

7. Recommendation

In grade 9 the science teachers should teach the basics of graphs required by the curriculum. Learners should be guided to draw graphs correctly and completely, e.g. with the appropriate scales, axes labels and graph headings.

They should also know how to calculate the gradient of a line graph and the area under a graph. They can then attach meaning to the gradients and areas of line graphs easily in grade 10 physical sciences. This can contribute to a smooth transition from grade 9 to grade 10.

The grade 10 science teachers must ensure the learners have the resources, the understanding, and the ability to transfer and connect grade 9 mathematics skills in grade 10.

On the other hand the grade 9 mathematics teachers must ensure proper understanding of gradient, variables, transfer and integration of mathematics skills in science.

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