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Interpretation of Student's Conceptual Understanding of Kinematics Concepts Using Factor Reduction

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Abstract - To understand student's conceptual understanding of kinematics concepts and graphical interpretation; we used a diagnostic tool called Kinematics Concepts Test (KCT). Relevant indices like Item difficulty index, Item discrimination index, Item point biserial coefficient, Kuder-Richardson reliability index and Ferguson's delta were calculated to evaluate the reliability and discriminatory power of the test. Exploratory factor analysis could identify major areas in which students have conceptual difficulty viz. kinematics concepts and interpretation of kinematics graphs especially in relating position, velocity and acceleration graphs when taught by traditional method.

Keywords: Kinematics Concepts Test, Kinematics graphs, Fergusson's Delta, Exploratory factor analysis

I. Introduction

Researchers suggest that traditional teaching method of classroom instruction and laboratory experimentation is not sufficient and that most of the students are confused about kinematics concepts and have severe difficulties in understanding line graphs (Berg & Smith, 1994; Scanlon, 1998). They are often unable to interpret the mass kinematics constructs in physics (e.g., Leinhardt, Zaslavsky& Stein, 1990). Students often misinterpret line graphs as paths of motion regardless of which kinematics concepts are taken into account by the graphs (e.g., McDermott, Rosenquist& van Zee, 1987). They find it difficult to understand the meaning of areas under different kinematics graphs (Berg, C. A., & Smith, P. 1994) and distinguish between a quantity and the change of that quantity (Lockhead, 1980).

An important component of understanding the connection between reality and the relevant graphs is the ability to translate back and for thin both directions "Line graph construction and interpretation are very important because they are an integral part of experimentation, the heart of science." (p. 572)(Danny Mccanzy). Graphical methods provide more physical insight than a set of equations (Resnik&Halliday).

We have designed the test with the purpose of identifying the student's misconceptions in kinematics and their understanding of kinematics graphs at the undergraduate level. (LalitaRane, 2016)Specifically, we wanted to examine the extent to which students could:

1. Differentiate average and instantaneous kinematical quantity,

2. Relate graph with corresponding real time motion and

3. Draw position-time graph from acceleration-time and velocity-time graphs and vice-versa using concepts learnt from their introductory classes' dealing with kinematics.

A factor analysis of response data of the test identified those major underlying concepts called factors which the students had understood well (that is answered most of the related questions correctly) or misunderstood and which need to be addressed in kinematics teaching methodology.

II. Materials and Methods (*Instruments)*

This study employed a multiple choice 23 items kinematics concept test (KCT) selected from 37 items following expert opinion from five senior teachers teaching mechanics at undergraduate level and on the basis of level of difficulty and the indices of defined differences. The test included a combination of qualitative and quantitative questions from the calculus-based undergraduate physics mechanics curriculum, which probed for

(1) Student's ability to interpret verbal representations in kinematics.

(2) Student's ability to interpret equations in kinematics.

(3) Student's ability to interpret graphical representations

The respondents for this study were first year undergraduate students (aged 18 to 20) from three different colleges affiliated to Pune University in the academic year. The total number of students selected from these colleges was 196.

Each question had one right answer and three wrong alternatives some of which could be chosen because the student had not understood the underlying concept or because of a prevailing misconception. The kinematic motion of objects is represented by the means of equations of motion, verbal descriptions, and tabular data orgy using graphs. All test items were intended to assess students' understanding of kinematics graphs and basic concepts of kinematics

III. Statistical Evaluation of KCT

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Five statistical tests were applied for assessment of the data from the sample, to examine the student's responses to individual test items in order to check the quality of those items and of the test as a whole. The statistical tests were as per the table below.

For items with one correct alternative worth a single point, the values of Item difficulty index (P), Item discrimination index (D), average Point biserial coefficient (r_{bps}) to measure of consistency of a single test item. With the entire test, Kuder-Richardson reliability index measure of internal consistency and Ferguson's delta to measure discriminatory power for KCT are given with their possible range in the table and are well within the range for KCT.

Table 1.**Overview of statistical results of KCT**

Test statistics	**Possible values**	**Desired values**	**Value for KCT**
Item difficulty index (P)	[0,1]	> 0.3	0.3867
Item discrimination index (D)	[-1,1]	> 0.3	0.4295
Point biserial coefficient (rpbs)	[-1,1]	> 0.2	0.3889
KR-21 test reliability (r)	[0,1]	> 0.7 or > 0.8	0.7115
Fergusson's delta (δ)	[0,1]	> 0.90	0.952

IV. Exploratory Factor Analysis

Factor analysis is a data reduction technique for analysing correlations between groups of observed variables to allow researchers to investigate concepts that are not easily measured directly. Factor analysis reduces multiple observed variables having similar patterns of responses into a few interpretable underlying factors which capture part of the overall variance in the observed variables. The relationship of each variable to the underlying factor is expressed by the so-called factor loading.

SPSS 15.0 program was used for the factor analysis. Factor analysis starts with construction of the correlation matrix between the set of items that are investigated. The standard Pearson correlation function is used to calculate the correlation matrix. The inter-correlation between items in KCT exceed 0.30, suggesting that there is enough communality and the data exhibits factorability (Tabachnick&Fidell, 2001).

The sample studied was large (N=196), had low percentage of missing data, outliers were removed and the data was checked for linearity - thus satisfying the assumptions for multivariate statistical techniques (Comrey, 1985; Pett et al., 2003). An additional assessment of factorability of data comes from Bartlett's Test of Sphericity, Kaiser-Meyer-Olkin(KMO) Test of sampling Adequacy and the value of determinant of correlation matrix. Table 2 reports the measures of factorability for correlation matrix of the data from KCT.

Table 2: Measures for assessing the factorability of correlation matrix

Measure	KCT Value
Determinant	1.68×10^{-44}
Bartlett's Test of Sphericity	$p << .0001$
Kaiser-Meyer-Olkin Test of sampling Adequacy	0.679

The KMO test of sampling adequacy measures the shared variance in the items and suggests that in the observed matrix the degree of common variance is on the upper boundary of middling (Friel, n.d.) .The standard rule is that the KMO-coefficient should be at least above 0.60 and the value calculated for the KCT found to be 0.679 and considered suitable for factor analysis. The determinant value of our matrix is very close to zero.

After confirming the adequacy and factorability of data, there are two stages of factor analysis: 1) *Factor extraction and 2) Rotation* of principal components to identify variables which explain factors more accurately.

For *factor extraction* and to identify the least number of factors which will explain maximum amount of variance method of Principal component analysis is used. The Principal component analysis includes all common variance, specific variance and error variance when examining the relationships (Castello and Osborne, 2005). The initial extraction assumed that each combination is orthogonal to the other. While determining the optimal number of factors, multiple criterion methods like eigen values, the Cattell's (1966) scree plot and the percent of extracted variance are used (Castello and Osborne, 2005, Schonrock-Adema et al., 2009).The Scree plot and eigen values suggests that our solution could require to retain 7-10 factors. We determined that the factor analysis solution with 8 factors gave the best conceptual interpretability and good loading for major variables in the factor and smaller cross loadings (Suhr, 2006).

Table 3: Explain results of 8 factor Promax and Varimax Cronbach's Alpha values

Promax				Varimax			
	1		**Cronbach's Alpha**				**Cronbach's Alpha**
Q2	0.780				1		
Q5	0.775			Q2	0.778		
Q17	0.687		**0.758**	Q5	0.772		
Q18	0.683			Q17	0.688		**0.758**
Q13	0.545			Q18	0.647		
Q22	0.446			Q13	0.563		
				Q22	0.489		
	2						
Q19	0.708				2		
Q11	0.615		**0.521**	Q19	0.693		
Q12	0.592			Q11	0.592		**0.462**
	3				3		
Q23	0.691			Q23	0.660		
Q15	0.491		**0.4**	Q15	0.517		**0.32**
Q6	0.482						
Q8	0.438				4		
				Q3	0.621		
	4			Q12	0.440		**0.352**
Q10	0.729		**0.186**				
Q3	0.676				5		
				Q16	0.729		
	5			Q21	0.726		
Q21	0.748			Q20	0.416		**0.432**
Q16	0.748		**0.438**				
Q20	0.391				6		
				Q14	0.698		
	6			Q4	0.487		**0.222**
Q14	0.813						
Q4	0.475		**0.222**		7		
				Q7	0.675		
	7			Q9	0.628		**0.335**
Q7	0.665						
Q9	0.649		**0.335**		8		
				Q1	0.874		
	8			Q10	0.371		**0.325**
Q1	0.892						
Q4	0.335		**0.278**				

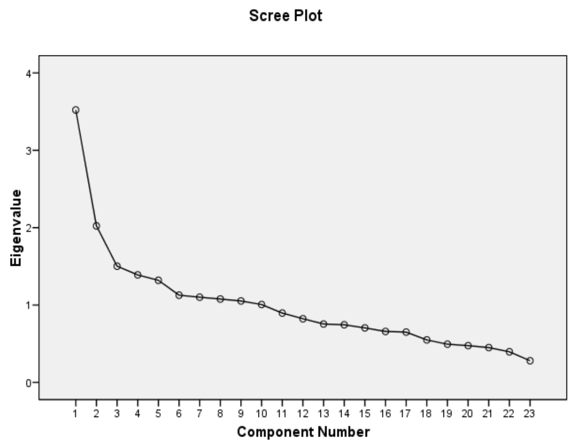

Figure 1.Scree Plot.

The figure demonstrates the screen plot of the eigen values of the Pearson correlation matrix and factors. The knee is between the factors seven and ten.

The 8 factor solutions with Varimax orthogonal factor analysis and Promax rotated factor analysis is shown in table 3. As we can see the Promax factors are better defined and were used for final analysis.

The second stage is the rotation of principal components to identify variables which explain factors more accurately and gives a simple structure solution with each factor represented by several items that load strongly on that factor only (Tabachnick and Fidell, 2001). We used Promax rotation method this allows oblique rotation and factors to be correlated. In our case, the Promax solution led to better interpretability and better loading for major factors (De Coster, 1998; Henson & Roberts, 2006). However the definition of factors did not change much.

With the number of factors to be retained decided, the items are factored again using Varimax rotation and the solution is further rotated in order to achieve an interpretable, statistically comparable and more meaningful solution (Child, 1990) using Promax.

Table 4: Correlation coefficients between factors in the non-orthogonal eight-factor model.

Component Correlation Matrix								
Component	1	2	3	4	5	6	7	8
1	1.000							
2	0.140	1.000						
3	0.173	-0.051	1.000					
4	0.047	-0.041	-0.058	1.000				
5	0.184	0.140	0.049	0.184	1.000			
6	0.020	-0.100	0.022	0.392	-0.007	1.000		
7	0.006	-0.069	0.013	0.071	0.026	0.128	1.000	
8	0.037	-0.018	-0.130	0.101	0.084	0.112	0.071	1.000

The non-orthogonal 8 factor model above gives correlation coefficients suggesting that the factors are almost independent and stand for genuinely different set of concepts or phenomena.

The sample size of this study is 196 with 23 items has subject to variable (STV) ratio more than 5 and is large enough to produce a reliable factor analytic solution(Shur, 2006; Zhao, 2009).

Table 5: Explain results of 8 factor Promax in terms of Concepts and skill sets required

Item	Factor								Corresponding Concept
	1	2	3	4	5	6	7	8	
Q2	0.780								Factor 1 Concept of integration
Q5	0.775								
Q17	0.687							Low P	
Q18	0.683								
Q13	0.545								
Q22	0.446	0.349							
Q19		0.708							Factor 2 Concept of velocity and acceleration as vector
Q11		0.615					0.312	High P	
Q12		0.592		0.455					
Q23			0.691						Factor 3 Concept of velocity and acceleration as rate
Q15			0.491					High to medium	
Q6			0.482						
Q8			0.438						
Q10				0.729				0.336	Factor 4 Concept of double integration
Q3				0.676					
Q21					0.748				Factor 5 Dual input graph and tabular data C8
Q16					0.748				
Q20			0.331		0.391				
Q14						0.813			Factor 6 Verbal description
Q4						0.475		0.335	
Q7							0.665		Factor 7 Calculation of acceleration from position time graph C4
Q9							0.649		
Q1								0.892	Factor 8 Kinematics equations
Q4								0.335	

V. Result and Discussion

The 8 factors solution as suggested by screen plot accounts for 56.79% of total variance in the data and all the item loadings are more than 0.3 indicating a good correlation between a particular item and the corresponding factor (Kline, 1994).The first factor groups together the six items related to the concept of area under the curve corresponding to the mathematical concept of first order integration. The item loadings are all between 0.446 and .780 meaning that these items have a high correlation with this factor. As suggested by the value of difficulty index of these items students find it difficult to interpret first level integrals from the graph. Thus suggests lack of knowledge of integration as a tool, non-familiarity with interpreting graphs by finding out area under the curve and possible lacuna in our curriculum where focus on graphic interpretation is absent. They find it difficult to interpret whether the object is speeding up or slowing down from the corresponding acceleration-time graph. Most of the students believe that the object speeds up if the acceleration is positive, and the object is slows down if the acceleration is negative.

The second factor mainly groups together the items which refer to the direction concept describing velocity and acceleration as a vector. The concept of direction as against purely scalar quantities is illustrated by this factor. There is difficulty in relating slope of x/t and v/t graph with direction of velocity and acceleration respectively. They think that if the speed is constant than acceleration is also constant. The item loadings are all between 0.592 and .708.

The third factor mainly groups together the items which refer to the concept of velocity and acceleration as rate. These items involve calculation and interpretation of slope. The motion of objects is demonstrated by the shape and the slope of the lines on a position vs. time graph. There is a difficulty in analysing position-time graphs by relating slope of the x/t graph and change in velocity. There is also difficulty in comparing the velocities of two objects. They think that if the object moves with a high speed then its acceleration is also high and if the object moves with a low speed then the acceleration is also low. Acceleration can be high, low or zero in high velocities. It is only related to the change in velocity. The item loadings are all between 0.438 and .691.

The factor 4 groups together the items which refer to the concept of qualitative description of motion involving double integration. Students have difficulty to draw position time graph of corresponding acceleration time graph which involves relating acceleration velocity and displacement together considering their magnitude as well as direction. Students do not recognize situations where they need to calculate area under the curve if there is no grid present. The item loadings are all between 0.455 and .729.

The factor 5 groups together the items which refer to the concept of velocity and acceleration as rate and vector when there is dual input- graphic as well as tabular. Students are comfortable with calculating slopes when calibrated graph or tabular data is given. The item loadings are all between 0.391 and .748.

The factor 6 groups together the items which refer to the concept of integration involving verbal description. The item loadings are all between 0.475 and .813

The factor 7 groups together the items which involves drawing acceleration time graph from position time graph. The item loadings are all between 0.649 and 0.655.
The factor 8 groups together the items which refer to the application of kinematics equations of 0.335 and 0.892.

VI. Conclusions

The aim of this study was to examine students' understanding of kinematics concepts and kinematics graphs. The average item difficulty index, average item discrimination index and average item point biserial coefficient calculated for the test indicates that Kinematics Concept Test (KCT) is sufficiently reliable item wise. The test reliability and Ferguson's delta values calculated for the test indicate that Kinematics Concept Test (KCT) is sufficiently reliable as whole test. The results of the test are indicative of a lack of conceptual mastery amongst undergraduate students of basic and familiar Kinematics concepts, particularly Kinematics graphical interpretation. It is necessary to use interactive teaching methods for proper understanding of these concepts (Coca, 2012). Microcomputer based laboratory (MBL), Computer simulations, animations and demonstrations may be useful in these respects. Physics educators should use these tools for interactive learning.

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