Factor Analysis and the Force Concept Inventory

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Abstract: Four sections of introductory physics (n=244) at the University of Northern Colorado took the Force Concept Inventory (FCI) both before and after instruction in Newtonian mechanics. Factor analyses of the results reveal several interesting contrasts that may shed some light on the development of concept organization in the introductory physics course. Post-test FCI results indicate that at the end of the semester student responses have become more closely aligned with the particular Newtonian concept associated with each question by the authors of the FCI.

Introduction: Two introductory physics classes are included in this investigation. They are the algebra-based course (PHYS 220) and the calculus-based course (PHYS 240). The two classes were taught by different professors in a rather traditional manner with four lectures and one three hour laboratory per week. The FCI was administered as a pre-test during the first laboratory meeting. The FCI was also administered during the last laboratory session of the semester. The same instructors taught the same courses for the years, 2008 and 2009. The data from both years is shown in the center column.

The authors of the FCI designed 30 questions on a variety of physics topics related to forces. Below are the primary classifications for each of the 30 questions as designed by the authors of the test.

Kinematics	First Law	Second Law	Third Law	Kinds of Force
9	6	21	4	1
12	7	22	15	2
14	8	26	16	3
19	10		28	5
20	17			11
	23			13
	24			18
	25			27
				29
				30

Factor analysis: Factor Analysis is a statistical technique used for finding patterns in large quantities of data. If we apply this method to the students' responses to the FCI, we are able to group the set of questions into various categories, or factors, dictated by the students' perspectives. Perhaps the most interesting aspect of factor analysis is that it classifies the factors not on the content of the question but on the patterns of the students' answers.

The most important factors are chosen by examining scree plots such as the one shown in the third column. Significant factors have eigenvalues in the region of the scree plot that departs from a general linear trend (eigenvalues >1) and account for the greatest percentage of the variance in student scores. In 2008 the 0.3 criteria was selected after examining the data. It represents approximately one-half of the highest loadings. We retained this criteria for the present analysis. Six factors seemed to be an appropriate compromise for all analyses. The center column shows data for the relevant factors, 2 – 6, for the 2008/2009 classes individually and combined.

Because all questions have positive loadings on factor 1 and 80% to 95% are above the chosen 0.3 criteria, we decided not to display factor 1 in the center column. We interpret this factor as reflecting the fact that the FCI is a test about introductory Newtonian physics.

2008

Pre

Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
A28 0.44	A4 0.42	A6 0.6	A1 0.37	A15 0.57
A20 0.36	A29 0.41	A3 0.48	A29 0.37	A28 0.33
A16 0.35	A26 0.37	A11 0.42	A22 0.35	
A10 0.33	A28 0.35	A12 0.31	A17 0.33	
A1 0.33	A18 0.33		A9 0.31	
A4 0.33				

Post

Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
A15 0.57	A6 0.67	A11 0.42	A1 0.54	A24 0.41
A17 0.51	A24 0.45	A29 0.41	A12 0.31	A15 0.41
A28 0.5	A7 0.44	A5 0.4	A5 0.31	
A4 0.48	A8 0.36	A17 0.33		
A25 0.38	A12 0.34	A18 0.32		
A16 0.34	A10 0.33	A10 0.31		

2009

Pre

Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
A4 0.55	A16 0.51	A29 0.53	A26 0.55	A2 0.52
A17 0.55	A19 0.39	A21 0.45	A20 0.51	A23 0.38
A15 0.55	A4 0.33	A22 0.35		
A28 0.5		A7 0.3		
A25 0.34				

Post

Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
A13 0.53	A17 0.73	A15 0.74	A20 0.34	A8 0.43
A5 0.53	A25 0.72	A4 0.44	A19 0.32	A23 0.34
A26 0.53		A28 0.31		
A18 0.52				
A11 0.51				
A30 0.43				
A25 0.33				

2008 + 2009

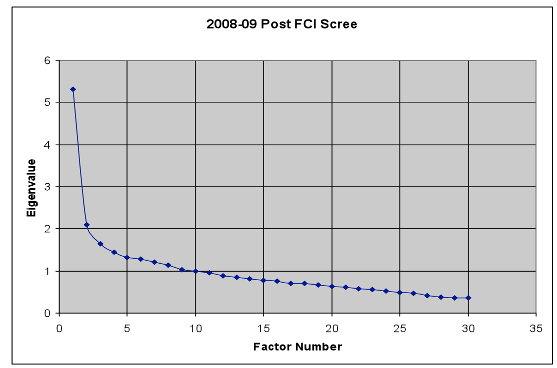
Pre

Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
A4 0.5	A16 0.5	A29 0.5	A24 0.4	A9 0.5
A17 0.5	A28 0.4	A21 0.3	A8 0.3	A27 0.4
A15 0.4	A4 0.4	A17 0.3		
A28 0.4	A1 0.3			
A25 0.4				

Post

Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
A13 0.5	A15 0.6	A17 0.6	A29 0.5	A21 0.6
A26 0.5	A4 0.5	A25 0.4	A18 0.27	A22 0.3
A18 0.5	A28 0.4	A8 0.4	A1 0.268	
A5 0.5	A17 0.4	A9 0.3	A5 0.23	
A11 0.4	A25 0.4			
A30 0.3				
A25 0.3				

Observations: There has been some criticism of the Force Concept Inventory concerning what it actually measures. According to Huffman and Heller[1], "It seems more likely that the inventory actually measures bits and pieces of students' knowledge that do not necessarily form a coherent force concept." Our results seem to agree with this assessment when discussing results of the pre-test. Those factors (other than factor 1) which seem to have a significant contribution appear to include a wide variety of questions which the authors of the test categorized under different physics concepts. However, upon examining the results of the post-test this statement becomes more difficult to defend. Post-test factors seem to be characterized by the questions with the highest loading being classified under the same physics concepts as identified by the test authors.



Conclusion: The above results do not mean that the students are identifying the exact same concepts as the authors, but it does imply that, after instruction, the students have begun to organize their knowledge in a more coherent way.

Hastens and Halloun[2] state that the results of the test should be taken as a whole. Indeed, factor 1 has a positive loading by all questions for both the pre- and post-test, and the explanation of the variance in the post-test has increased significantly from the pre-test (31% vs. 18%,). This implies that the test does become a better overall measure after instruction. What that actually measures might be open to some dispute, but it certainly could be argued on face value that it is measuring the concept of force.

1 Huffman and Heller, *Phys. Teach.* **33**, 138-143 (1995)

2 Hastens and Halloun, *Phys. Teach.* **33**, 502-506 (1995)