UNIVERSITY of NORTHERN COLORADO

Fine Structure of the Force Concept Inventory

by
Courtney W. Willis, Richard D. Dietz, Matthew R. Semak
Physics , University of Northern Colorado, Greeley, CO 80639

Abstract: At the start of the 2007 fall semester, two introductory physics classes (n = 114) at the University of Northern Colorado took the Force Concept Inventory (FCI) and the Lawson Classroom Test of Scientific Reasoning Ability. Both groups also took the FCI again at the end of the semester. Information about each student's gender and high school preparation in mathematics and physics was also collected. Several previous investigations of the improvement in FCI scores (and its correlations) have focused only on the total score. We present an analysis of the students' improvement on each question on the FCI and how it correlates with other factors.

Introduction: The two classes included in this investigation were 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 Lawson Test was also given at that time. The FCI was also administered during the last laboratory session of the semester. Originally 114 students were included in this study. Problems with missing data and other irregularities led to the inclusion of data from only 90 students in the analysis we present here.

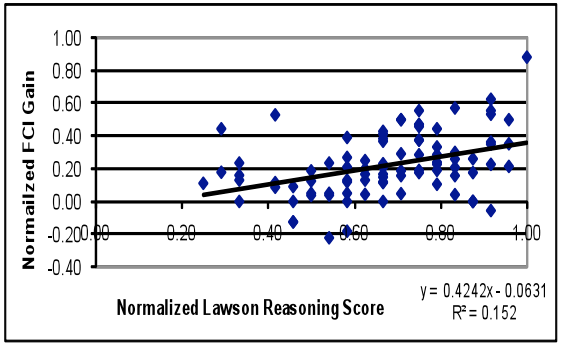
	Lawson Mean	FCI Pre Mean	FCI Post Mean
Algebra PHYS 220 n=55 Fn=37 Mn=18	**0.642** F=0.617 M=0.694	**0.274** F=0.244 M=0.335	**0.400** F=0.366 M=0.470
Calculus PHYS 240 n=35 Fn=11 Mn=24	**0.725** F=0.746 M=0.717	**0.402** F=0.270 M=0.463	**0.577** F=0.406 M=0.656
Total Students n=90 Fn=48 Mn=42	**0.675** F=0.647 M=0.707	**0.324** F=0.250 M=0.408	**0.469** F=0.375 M=0.576

The graph below shows the Normalized FCI Gain as a function of the Lawson reasoning score. We adopt the definition of normalized gain advocated by Bao (2006) defined as follows:

If Post ≥ Pre then **G = (Post – Pre)/(1-Pre)**

If Post < Pre then **G = (Post – Pre)/(Pre)**

The positive correlation between the FCI Gain and Lawson Score is consistent with the results reported by Colette and Phillips (2005).

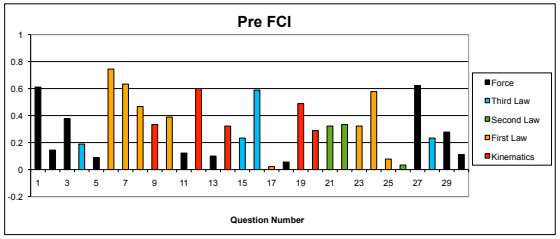


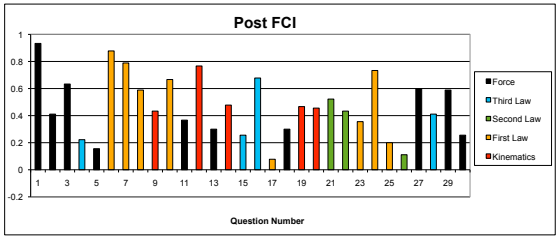
Hestenes has suggested that particular concepts of Newtonian physics are related to specific questions on the FCI according to the following table.

Newtonian Concepts in Force Concept Inventory

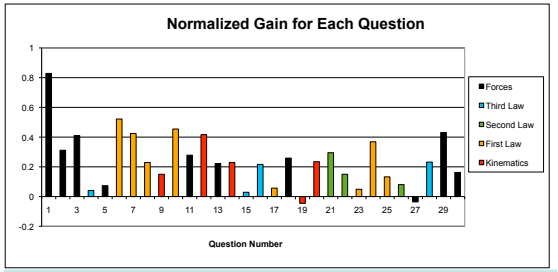
Kinematics	**9,12,14,19,20**
First Law	**6,7,8,10,17,23,24,25**
Second Law	**21,22,26**
Third Law	**4,15,16,28**
Kinds of Force	**1,2,3,5,11,13,18,27,29,30**

The bar graphs below show how the total population of students performed on each of the 30 questions on the FCI. The vertical axis represents the fraction of the population responding correctly to a question. Colors are used to reflect Hestenes's categorizations.





The following graph shows the normalized gain for each question. **First Law** and **Force** (black) questions had the highest average gain (≈0.29), **Kinematics** and **Second Law** questions had middle averages (≈0.19), and the **Third Law** questions had the lowest average gain (≈0.13). The easiest questions have the highest gains which is a reflection of the definition of G and suggests a that better metric for gauging improvement is needed.



Factor Analysis is a statistical technique used for finding patterns in large quantities of data. When we apply this method to our FCI data we are able to group the questions into various factors. Since we are looking for patterns in the students' responses, it is the students' perspectives on the the subject matter that will dictate the factors. We interpret factor 1 as reflecting the fact that the FCI is a test about introductory physics and thus ignore it.

Factor Analysis Pre

Factor 2		Factor 3		Factor 4		Factor 5	
Q28	0.44	Q4	0.42	Q6	0.60	Q1	0.37
Q20	0.36	Q29	0.41	Q3	0.48	Q29	0.37
Q16	0.35	Q26	0.37	Q11	0.42	Q22	0.35
Q10	0.33	Q28	0.35	Q12	0.31	Q17	0.33
Q1	0.33	FQ8	0.33			Q9	0.31
Q4	0.33						

When Factor Analysis is applied to the pre and post results of the FCI an interesting result emerges. The factors identified in the pre-test show no relation to the Newtonian concepts being tested. In the Factor Analysis of the post-test results factor 2 is strongly related to the 3rd law, factor 3 to the 1st law, and factors 4 and 5 to kinds of force. This may be interpreted as a sort of crystallization of student thinking arising as a result of instruction.

Factor Analysis Post

Factor 2		Factor 3		Factor 4		Factor 5	
Q15	0.57	Q6	0.67	Q11	0.42	Q1	0.54
Q17	0.51	Q24	0.45	Q29	0.41	Q12	0.31
Q28	0.50	Q7	0.44	Q5	0.40	Q5	0.31
Q4	0.48	Q8	0.36	Q17	0.33	Q15	0.30
Q25	0.38	Q12	0.34	Q18	0.32		
Q16	0.34	Q10	0.33	Q10	0.31		