Conceptual Understanding of Forces Among Physics Majors

Robert C. Roleda
Science Education Department, De La Salle University
2401 Taft Avenue, 1004 Manila

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Conceptual understanding of forces among physics majors at De La Salle University were evaluated using the Force Concept Inventory (FCI). The FCI scores were found to vary from an average of 23.0% for freshmen to 39.74% for seniors. Only one out of 81 physics majors of all year levels was found to be a clearly Newtonian thinker. While there is a marked difference in the understanding of inertia and falling bodies between freshmen and seniors, conceptual understanding of kinematics, Newton's 2nd and 3rd Laws, and force identification did not reach the 50% level from first to fourth year.

INTRODUCTION

Physics instructors often feel dismayed with how little students learn in their introductory college physics courses and this is often reciprocated by students who fear and dislike physics courses. Researches in the past two decades on physics education have shown that students enter the course with preconceptions based on their own experiences with the physical world, and from what they may have learned in high school and grade school[1]. At the end of the course, students who passed may have learned to solve physics problems but many retain their non-scientific conceptions and few could explain physical process or phenomena scientifically[2,3]. The inadequacy of traditional physics instruction in developing conceptual understanding has led some physicists to advocate a scientific approach to teaching[4,5]. In the past two decades, researches on understanding how students learn[3,6-11] has led to numerous innovations to promote a more meaningful learning[12-14], many of which share the common feature of getting students actively involved in the learning process.

As physics is acknowledged to be an intellectually challenging discipline, it takes time for students to absorb abstract concepts. Physical concepts are therefore taken in at least two levels in undergraduate physics curricula: an introductory- level course which often is identical to those taken by engineering and other science students, and an intermediate-level course where the same concepts are studied with more depth. It is therefore hoped that as a student progresses to the junior and senior level, and matures intellectually, the physical concepts are better understood. In this paper, we investigate how physics majors' understanding of a physical concept change as they go through four levels of studies: (1) before taking the first college-level physics course; (2) after taking the first course in college physics; (3) after completing the introductory-level courses and just before taking the intermediate-level courses in physics; and (4) after taking more than half of the intermediate-level courses in physics.

Mechanics forms the foundation of the physics curriculum since it provides the framework through which we understand physical phenomena, and the central concept of Newtonian mechanics is force. A test of students' understanding of forces is then a good probe of how well future physicists are being trained. A test for such purpose called the Force Concept Inventory (FCI) has been developed by Hestenes *et al*[15] and administered to more than 20,000 students spanning from high school to graduate school[16,17]. In this paper, I used the revised 30-item version of the test found in the Arizona State University website[18].

METHODOLOGY

A. Gathering of Data

The Force Concept Inventory (FCI) was administered to all undergraduate physics majors of De La Salle University who were taking physics courses during the last trimester of schoolyear 1998-1999. The students were classified as follows:

- *Freshmen*: students who were taking their first physics course, in which forces are discussed
- *Juniors*: students who have finished all introductory-level physics courses and enrolled in their first intermediate-level physics course
- *Seniors*: students who have taken more than half of the intermediate-level physics courses.

The FCI was administered during the first week of classes to freshmen and juniors so that they could be regarded as those who have not yet taken a college physics course, and not yet taken an intermediate-level physics course, respectively. After taking the test, the freshmen were interviewed to explain their answers on some items. The freshmen were also given a post-test at the end of the trimester. Having completed one schoolyear of studies, the results of the freshmen post-test are regarded for the purposes of this study as the results of the following:

- *Sophomores*: students who have taken their first course in college physics.

In this study therefore, freshmen refer to physics majors at the beginning of their third trimester of study, sophomores refer to physics majors at the end of their third trimester of study, juniors at the beginning of their sixth trimester, and seniors at the beginning of their ninth term of study and those who are already in their twelfth trimester in the university.

B. Data Analysis

The total score of each student in the FCI test were computed. In addition, the test items were categorized according to topic and a table of specifications, shown in table 1, was prepared. The students' scores in each area were computed, and descriptive statistics per year level per topic were used to analyze the data. We assume in this study that the average scores of two groups of students in the same year level will be essentially the same. For purposes of analysis therefore, the junior level average score, for example, could be taken as the average score that the freshmen in the study would have once they reach the junior level.

Table 1. Table of Specifications for the FCI.

Label	Topic	Item No.
KI	Kinematics	19, 20
FB	Falling Bodies	1, 2, 3, 12, 14
L1	1st Law	6, 7, 10, 23, 24, 27
L2	2nd Law	8, 9, 17, 21, 22, 26
L3	3rd Law	4, 15, 16, 25, 28
FI	Identifying Forces	5, 11, 13, 18, 29, 30

Hestenes *et al's* taxonomy of misconceptions[15] was reviewed and modified to suit the revised version of the test. Because some misconceptions appear to be so closely related to one another, interviews with students were studied to validate the categorization. The resulting taxonomy of alternative conceptions is shown in table 6, and this was used to help identify the alternative conceptions of the students.

Gains in individual test scores are evaluated using the Hake factor[17]

$$g = \frac{(\%\text{score } 2 - \%\text{score}1)}{(100 - \%\text{score}1)}$$

which is a normalized measure of gain, defined as actual gain divided by the maximum possible gain. Gains of < 30% are characterized as low gain, $30\% < g < 70\%$ is considered medium gain, and $g > 70\%$ is classified as high gain[17,19].

Losses on the other hand are measured using the standard %change

$$\delta = \frac{(\%\text{score } 2 - \%\text{score}1)}{(100 - \%\text{score}1)}$$

as this is also normalized in the sense of being the actual loss divided by the maximum possible loss.

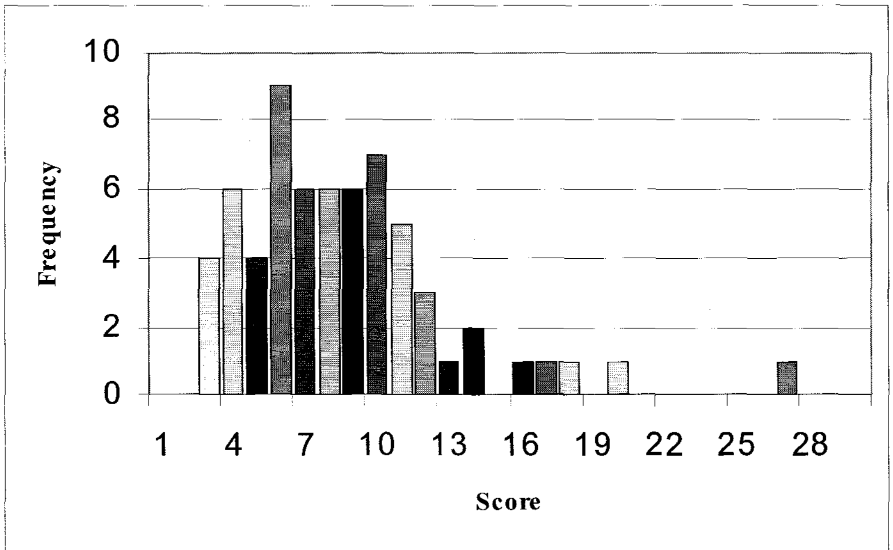
RESULTS AND DISCUSSION

A. Conceptual Understanding

The multiple-choice test called FCI was administered to all physics majors of De La Salle University taking physics courses during the third trimester of schoolyear 1998-1999. A total of 89 responses were gathered. While the test encourages leaving answers blank instead of guessing, 8 responses were discarded for having at least 20% of the 30-item 5-choices test left blank. From a total population of 81, 20 were identified as freshmen, 24 as sophomores, 24 as juniors, and 13 as seniors.

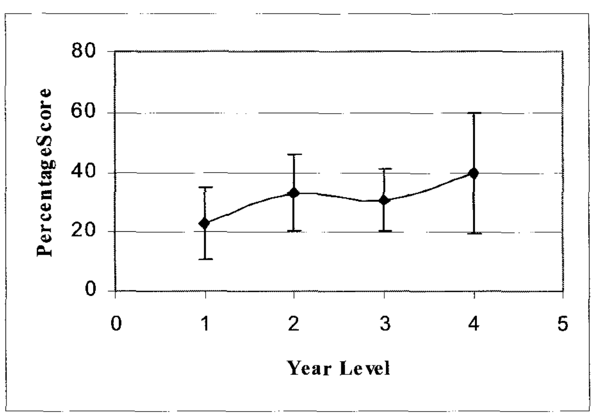
Figure 1 shows the frequency chart of the FCI scores. The sophomore scores were not included because these are actually the post-test scores of the freshmen. We note that the distribution is negatively skewed with an arithmetic mean of 9.0 and standard deviation of 4.4. The mean corresponds to a mere 3.0 points or 10% above the chance score, indicating a generally poor understanding of forces.

Figure 1. Frequency chart of the total FCI score. Sophomore scores were not included. N = 57 and the perfect score is 30. The lone physics major with the score of 28 was a senior who eventually graduated magna cum laude.



Studying the average FCI percentage score per year level, we note a general upward trend with a slight dip between the sophomore and junior levels in figure 2. The gain after instruction in the first physics course is 44.9%. The rise in average test score can be attributed to the fact that topics covered in the FCI are precisely the topics discussed in the first physics course. Part of the rise in test score may however be attributed to the fact that the sophomore test scores are actually the post-test scores of the freshmen. Although the degree to which retaking of the test affected the second test scores cannot be inferred from the data gathered, we should note that the 30-item FCI is a 30-minute test so that the time allotment was just sufficient for the students to answer the test items. Familiarization with test items can therefore be assumed to be not the major factor in the rise in test scores.

Figure 2. Average FCI percentage score per year level, with variability bars of $\pm\sigma$.



A dip corresponding to a loss of 8% between sophomore and junior levels may be attributed to a retention loss as forces are applied but not explicitly studied in the other introductory-level courses the juniors took. It is also quite possible that the sophomore scores are inflated because their scores are actually the post-test scores of the freshmen and so a part of the dip could be attributed to the effect of test familiarization among sophomores. The fact that there was no gain between sophomore and junior level compared to gains achieved in other year-level transitions indicate that non-mechanics introductory-level courses did not play a significant role in enhancing student understanding of forces.

Table 2. FCI average scores per year level. KI refers to kinematics, FB to falling bodies, L1 Newton's first law, L2 Newton's second law, L3 Newton's third law and FI force identification.

Year	KI	FB	L1	L2	L3	FI	Total
1	12.5	32.0	30.0	21.7	25.0	11.7	23.0
2	29.2	40.8	40.3	30.6	34.2	23.6	33.33
3	29.2	42.5	50.0	22.2	23.3	16.7	30.69
4	38.5	66.2	57.7	23.1	32.3	23.1	39.74

The gain of 29.5% from junior to senior year may be attributed to reinforcement of conceptual understanding in intermediate-level physics courses where the same concepts are taken up at a deeper level. The cumulative gain from first to fourth year is 72.8%. While these gain figures may look impressive, we should note that the fourth-year average FCI score is still a low level of 39.74%. The percentage gains are high simply because the freshmen started out with a very low average of 23%, which is slightly higher than the chance score of 20%.

Table 3. Gain/Loss in average score per year level. KI refers to kinematics, FB to falling bodies, L1 Newton's first law, L2 Newton's second law, L3 Newton's third law, and FI force identification.

Year Interval	KI	FB	L1	L2	L3	FI	Total
1 to 2	133.3	27.6	34.3	41	36.7	11.7	44.9
2 to 3	0	4.1	24.1	-27	-32	23.6	-8
3 to 4	31.9	55.7	15.4	3.8	38.5	16.7	29.5
1 to 4	207.7	106.7	92.3	6.5	97.8	23.1	72.8

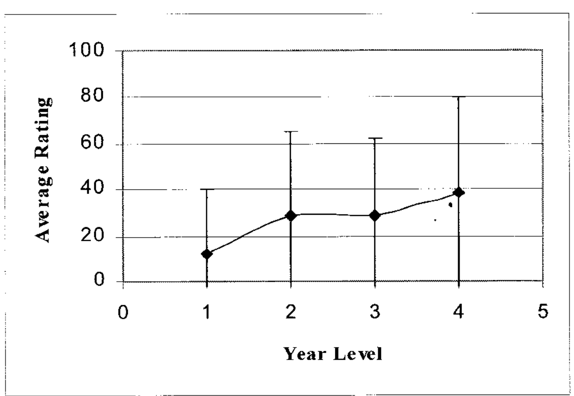
Figures 3 (b) and (c) show marked increases in students' conceptual understanding of falling bodies and Newton's First Law (inertia), with four-year cumulative gains of 107% and 92.3%, respectively, and good retention from year level 2 to 3. While there is a 208% gain and good retention in the conceptual understanding of kinematics as shown in figure 3(a), the average scores remained below 40% at the end of four years. In my classroom experience, students usually find less trouble in solving kinematics problems. This seems to indicate formulaic learning, with students able to work with the algebraic kinematics equations but unable to fairly discriminate between displacement, velocity, and acceleration when presented pictorially.

On the other hand, we see from figures 3 (e) and (f) substantial lack of retention with losses of 32% and 29% in the understanding of Newton's third law (action-reaction) and force identification, respectively. Seniors failed to even match the sophomore scores, indicating the failure of intermediate-level courses to build on the conceptual understanding in these areas. Four-year cumulative gains in these areas are 29.2% and 97.8%, respectively and the fourth-year average of 23.1% in identifying forces is marginally higher than the chance score of 20%.

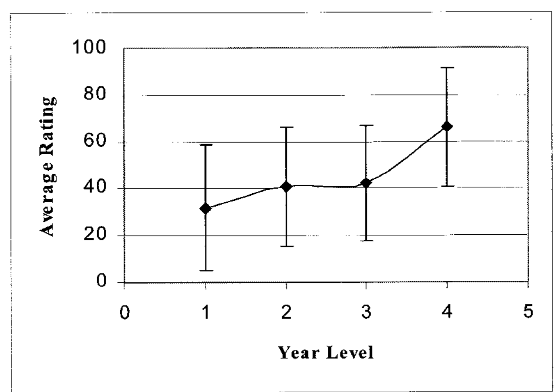
As shown in figure 3(d), the physics majors had an improvement of 41% in the understanding of Newton's second law after completing their first course in physics, but there is no apparent retention of this knowledge. Four-year cumulative gain in this area is a flimsy 6.5%, with fourth-year score of 23.1%, suggesting that preconceptions in this area are very strongly held, and were hardly affected by four years of physics instruction.

Figure 3. Average rating per year level on (a) Kinematics (b) Falling Bodies (c) Newton's First Law (d) Newton's Second Law (e) Newton's Third Law and (f) Identifying Forces (with variability bars of $\pm\sigma$).

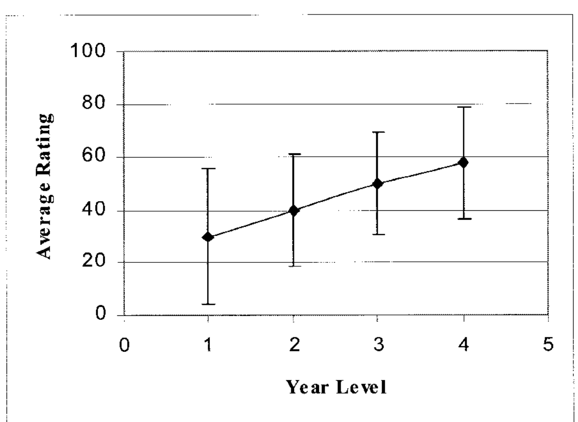
(a) Kinematics



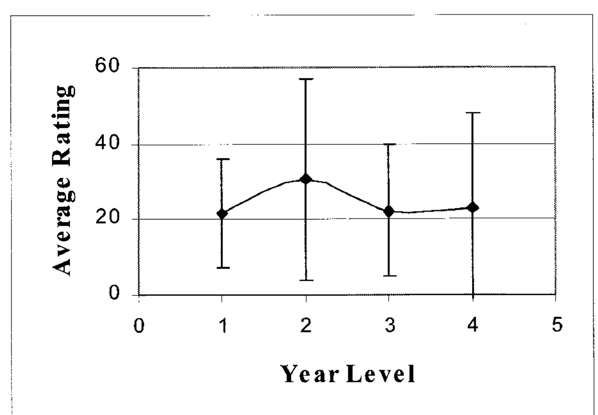
(b) Falling Bodies



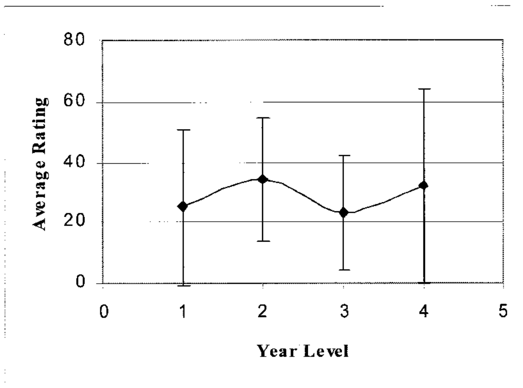
(c) Newton's First Law



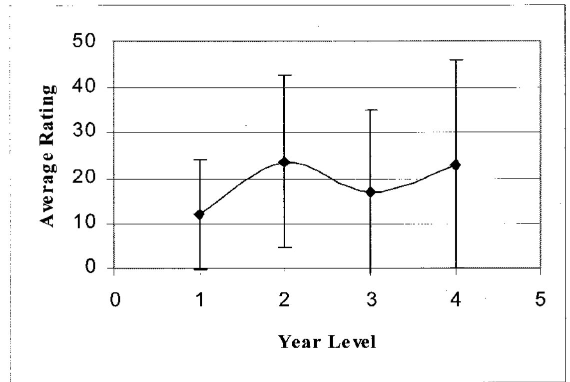
(d) Newton's Second Law



(e) Newton's Third Law



(f) Identifying Forces

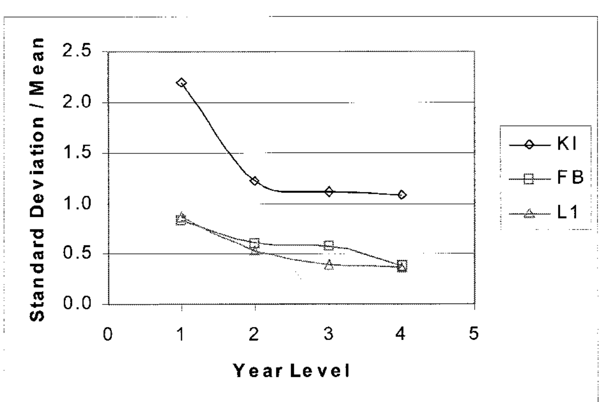


B. Effects of Instruction

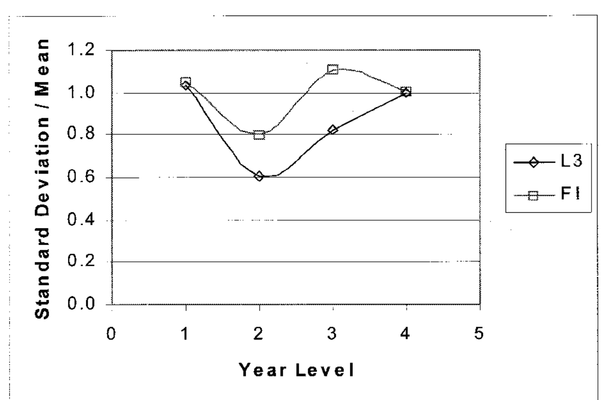
Effects of instruction may be gleaned from the distribution of the student test scores. Variation in test scores are measured by the normalized standard deviation of test scores, computed by dividing standard deviation by the arithmetic mean. As demonstrated in figure 4 (d), freshmen scores are expected to generally have a larger variance since they come from different backgrounds. As the students undergo the same treatment, like studying the same subjects under the same institution, it is reasonable to expect some form of homogenization to take place within the population, leading to a diminishing in the variance of their test scores. Having different instructors could on the other hand, result in an increase in variance of test scores. The large variance in the seniors' scores in figure 4 (d) may be attributed to the fact that they are composed of two batches of students: those who are close to graduation, and those who are just half-way through their upper-level physics courses. The two sets of students were grouped together in this study because of their small population sizes.

Figure 4. Variation of the test scores. Standard deviation per arithmetic mean for each year level on (a) kinematics, falling bodies and Newton's first law, (b) Newton's third law and force identification, (c) Newton's second law, and (d) the total FCI score

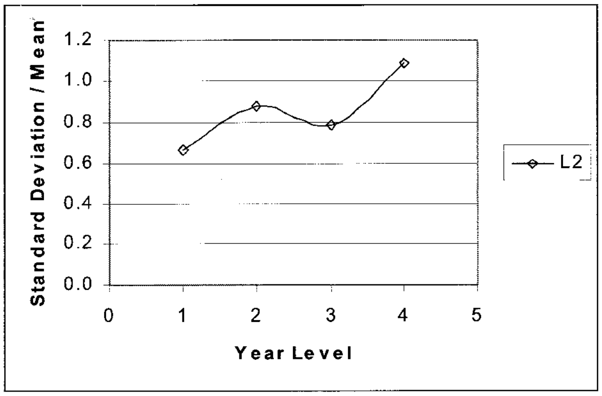
(a)



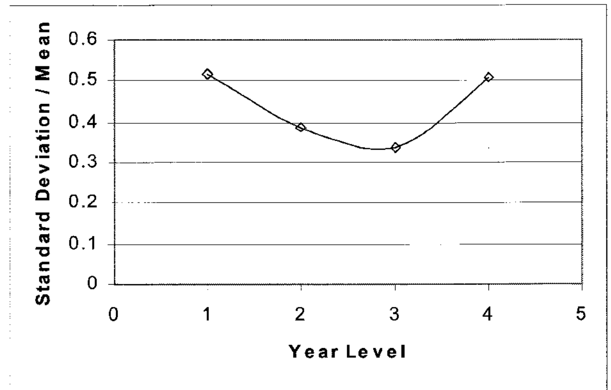
(b)



(c)



(d)



A dip in the standard deviation over mean chart indicates a homogenization of test scores or the diminishing of normalized variance in test scores. Homogenization thus indicates the tendency of students to have the same amount of correct answers and could well be interpreted that instruction or treatment had an impact. A rise in the standard deviation over mean chart on the other hand, could well be interpreted as instruction or treatment causing students to understand the topic differently, thereby leading to the tendency of students to have different amount of correct answers.

Figure 4 shows that except for Newton's second law, there is a significant homogenization of test scores after the students take their first college physics course. As seen from figure 4(a), in areas where test scores increased monotonically from first to fourth year, the variation levels dipped from first to second year indicating a homogenization of test score. The variation levels are maintained from second to fourth year, suggesting the stability of concepts learned. This learning stability helps explain why test scores in kinematics, falling bodies and Newton's first law rose from first to fourth year. Further homogenization shown between third and fourth year in the understanding of falling bodies suggests enhancement of conceptual understanding in intermediate-level courses, which could also explain the comparatively high scores of the seniors in this area.

Table 4. Standard deviation divided by arithmetic mean for FCI average scores in each year level. KI refers to kinematics, FB to falling bodies, L1 Newton's first law, L2 Newton's second law, L3 Newton's third law, and FI force identification.

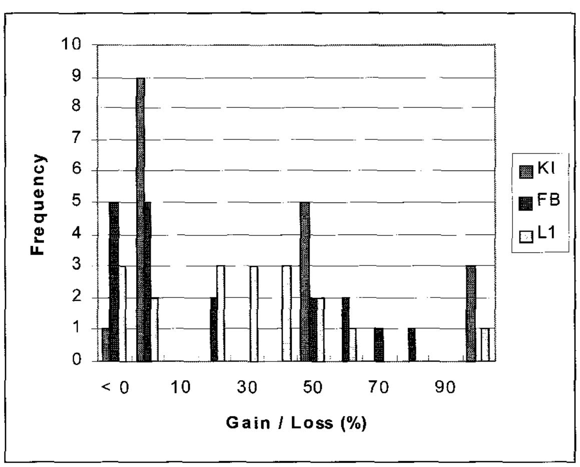
Year	KI	FB	L1	L2	L3	FI	Total
1	2.200	0.846	0.876	0.665	1.034	1.047	0.517
2	1.230	0.621	0.531	0.876	0.61	0.804	0.387
3	1.121	0.577	0.393	0.787	0.826	1.103	0.337
4	1.082	0.378	0.366	1.085	0.996	1.002	0.508

Instruction in the first physics course seems to have had a significant effect on the conceptual understanding of Newton's third law and force identification, as evidenced by the dips in figure 4 (b). This fact supports our earlier finding of improvement in conceptual understanding as evidenced by test scores in these areas from freshmen to sophomores. Subsequent rise in the variation levels suggest that concepts learned were unstable, which could help explain the big losses shown in figures 3 (e) and (f). The dip in the variation level from third to fourth year in force identification suggests reinforcements of the concepts in intermediate-level courses. The high level of standard deviations however suggests non-uniform learning among different students, which might explain why the senior average score did not surpass sophomore average scores in this area. The continued rise in variation level from third to fourth year in Newton's third law suggests that intermediate-level courses do not address this concept explicitly. The rise in test scores however, indicates a relearning of this concept through some indirect means.

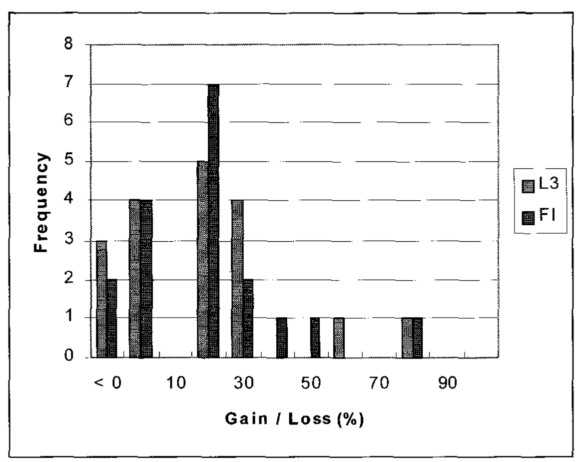
The general upward trend in the variation level of test scores in Newton's second law shown in figure 4 (c) suggests the ineffectiveness of instruction, supporting our earlier observation that the rise in test scores is lowest in this area. After taking their first physics course, students ended up more varied in their understanding of this concept. While the test scores went up by 41%, the rise represents an appreciation of the correct answer, but not a conceptual understanding. This is supported by the fact that the variation level dipped from second to third year, paralleled by a drop in test scores to pre-instruction levels as shown in figure 3 (d). It seems then that after appreciating the correct answer, accommodation of the scientific concept did not take place and the dip represents the reversion of students to their preconceptions as if no instruction took place at all.

Figure 5. Gain/Loss in student scores from pre-test to post-test on (a) kinematics, falling bodies and Newton's first law (b) Newton's third law and force identification (c) Newton's second law, and (d) the total FCI score (*N*=18)

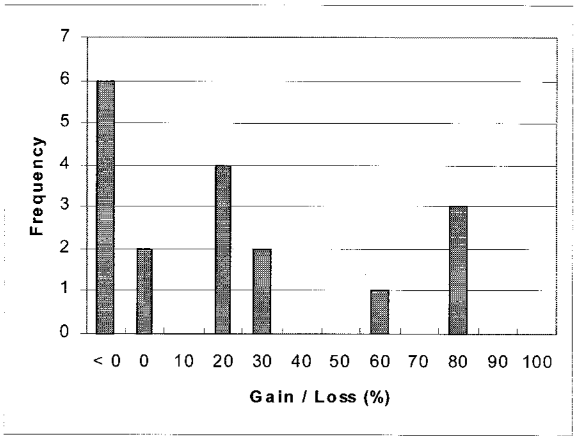
(a)



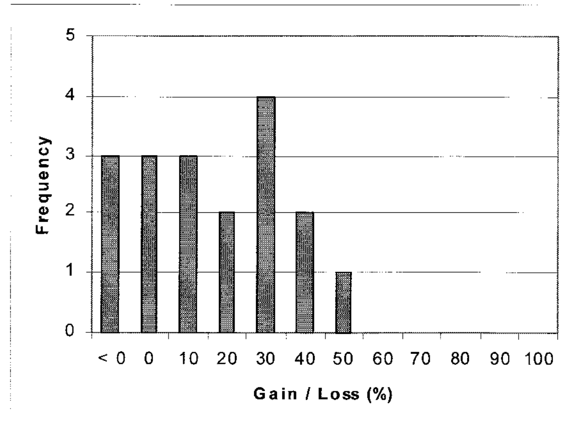
(b)



(c)



(d)



The effects of instruction particularly in the first physics course may also be viewed from the gain/loss of students who took the pre-test and post-test. The scores involved are the freshman and sophomore scores in this study. Computing the gain/loss per student, we see from figure 5 (d) that almost equal number of students are found in each gain interval from <0 to 50. On the whole, the effect of instruction is positive but low with an average gain of 16%.

Average gain is highest for kinematics at 25%, but this is tempered by a very widely spread and negatively skewed distribution as shown in figure 5 (a), which may explain our earlier observation of low improvement in the understanding of this concept. Average gain in Newton's first law is next highest at 20.5%, supporting our earlier observation of improved understanding in this area. Curiously for falling bodies, the area where students fared best after four years, the average gain is a measly 7.8%, with majority of the students found in the 0 and <0 intervals. A closer look at table 3 reveals that significant increase in understanding of this concept occurred during the junior-senior interval rather than the freshman-sophomore interval, suggesting that enhancement in understanding of this concept may be attributed more to the intermediate-level courses rather than the introductory course.

Table 5. Average and standard deviation of gains by students who took their first college physics course, from pre-test to post-test. KI refers to kinematics, FB to falling bodies, L1 Newton's first law, L2 Newton's second law, L3 Newton's third law, and FI force identification. ($N = 18$)

Year	KI	FB	L1	L2	L3	FI	Total
Average	0.250	0.078	0.205	0.043	0.115	0.118	0.160
SD	0.479	0.487	0.375	0.513	0.338	0.368	0.204

Negatively skewed distributions and low-average gains in Newton's third law and force identification support our earlier observations of low conceptual attainment and low retention rate in these areas. In figure 5(c), we note that 44% students suffered loss in test scores and another 11% had zero gains in test items on Newton's second law. This finding is consistent with our earlier contention that instruction had a negative influence on the understanding of the topic. Together with the big standard deviation of 51.3%, this finding supports our earlier observation that introductory-level instruction led students to have a more varied conception of the topic.

C. Alternative Conceptions

Students' alternative conceptions in mechanics has been a subject of some researches [3,20,21]. Having used the FCI as our instrument, alternative conceptions probed in this study are similar to those made by Hestenes, et al.[15]. Validation through interviews with freshmen subjects in the study however led to a modification of the taxonomy of alternative conceptions prepared by Hestenes et al.[15] This modification is reflected in table 6. Items that probe whether Newtonian concepts were not recognized or not by students are listed in table 7.

Table 6. Taxonomy of Alternative Conceptions probed by FCI. Presence of alternative conception is suggested by selection of the corresponding inventory item.

Alternative Conception	Inventory Item
Kinematics	
K1. Position-velocity undiscriminated	19B,C,D
K2 Velocity-acceleration undiscriminated	19A; 20B,C
Impetus	
I1. Impetus supplied by "hit"	5C, D, E; 11B,C; 18,C,D,E; 27D; 30B,D,E
I2. Loss / recovery of original impetus	7D; 8C,E; 21A; 23A,D,E
I3. Impetus dissipation	10C,E; 12C,3; 13A,B,C; 14E; 24C,E, 27B
I4. Gradual / delayed impetus build-up	8D; 10B,D; 21D; 26C; 27E
Active Force	
AF1. Only active agents exert forces	15D; 16D; 28B
AF2. No motion implies no force and vice versa	27A; 29E
AF3. Velocity proportional to force	3B; 7B; 22A; 26A
AF4. Force causes acceleration to terminal velocity	3A; 22D; 26D
AF5. Active force wears out	22C,E
Action / Reaction Pairs	
AR1. Greater mass implies greater force	4A,D; 15B; 16B; 28D
AR2. Most active agent produces greatest force	15C; 16C; 28D
Concatenation of Influences	
CI1. Largest force determines motion	17A,D
CI2. Force compromise determines motion	6D; 7C; 12A; 14C; 21C
CI3. Last force to act determines motion	8A; 9B; 21B; 23C
CI4. Circular motion continuance	6A; 7A
CF. Centrifugal force	5E; 6C,D,E; 7C,D,E; 18E
OB. Obstacles exert no force	4C; 15D,E; 16D,E
Resistance	
R1. Motion when force overcomes resistance	25B,D,E
R2. Weight resists horizontal motion	25A,B,E
Gravity	
G1. Air pressure-assiste gravity	3E; 17D; 29D
G2. Natural tendency of objects to rest on earth's surface	3D; 13E
G3. Heavier objects fall faster	1A,D; 2B,D
G4. Gravity increases as objects fall	3B; 13B
G5. Gravity acts after impetus wears down	12E; 13B; 14E

Table 7. Newtonian concepts not recognized by students. Failure to recognize the concepts in a given situation is suggested by selection of the corresponding inventory item.

Unrecognized Newtonian Concepts	Inventory Item
NF. Normal force	5A,C,E; 11A,B; 29A
NI. Inertial motion	8A; 14A,B; 21B; 27A

Students whose answers correspond to those listed in the second column of tables 6 and 7 were given a mark of 1.0 for each correspondence. A student's score in each concept item listed in the taxonomies are then taken by summing the marks and then divided by the number of question items involved in the concept item. The concept scores are then averaged per year level, and the results are shown in table 8.

Table 8. Average score per year level on alternative concepts and Newtonian concepts probed in the study. High scores imply the prevalence of alternative concepts or non-recognition of Newtonian concepts listed in tables 6 and 7, respectively.

	1	2	3	4
K1	0.400	0.500	0.375	0.385
K2	0.425	0.292	0.333	0.385
I1	0.670	0.708	0.650	0.646
I2	0.250	0.188	0.167	0.135
I3	0.383	0.306	0.319	0.282
I4	0.160	0.167	0.108	0.138
AF1	0.15	0.125	0.083	0.051
AF2	0.25	0.146	0.250	0.269
AF3	0.425	0.490	0.448	0.500
AF4	0.150	0.111	0.139	0.154
AF5	0.100	0.125	0.083	0.077
AR1	0.213	0.219	0.385	0.231
AR2	0.450	0.403	0.528	0.590
CI1	0.700	0.583	0.833	0.692
CI2	0.080	0.050	0.075	0.077
CI3	0.350	0.427	0.396	0.308
CI4	0.450	0.292	0.292	0.154
CF	0.188	0.208	0.219	0.269
OB	0.100	0.069	0.097	0.000
R1	0.95	0.750	0.833	0.846
R2	0.700	0.292	0.458	0.308
G1	0.200	0.083	0.278	0.154
G2	0.200	0.167	0.292	0.000
G3	0.475	0.313	0.375	0.115
G4	0.600	0.396	0.438	0.192
G5	0.233	0.125	0.167	0.051
NF	0.433	0.319	0.319	0.385
NI	0.563	0.500	0.510	0.423

Test results show that physics majors across all year levels carry alternative conceptions I1 (impetus supplied by hit), CI1 (largest force determines motion), and R1 (motion occurs when force overcomes resistance) with average year level score exceeding 50% for each of these concepts and R1 registering a high 84.5%. These common-sense concepts are reflective of the medieval concept of force-impetus whereby motion is possible only in the presence of a sustaining force. This result corroborates Halloun and Hestenes's observation that common-sense conceptions of students are closer to the medieval concept of impetus than the Aristotelian notion of force [1], and contradicts the myth that misconceptions in physics are Aristotelian.

Four years of study hardly affected the students' common sense conception of force-impetus. Although the year-level average in NI (non-recognition of inertial motion) decreased monotonically from 56.3% to 42.3%, the persistently high averages of 64.6%, 69.2% and 84.6% in I1, CI1 and R1 at the senior level suggests strong retention of the common sense conception of impetus and incomplete assimilation of the most fundamental Newtonian concept, inertia, even after years of exposure to Newtonian and post-Newtonian physics. This finding is supported by the anomalous result for the alternative concept AF3 (velocity is proportional to force) whereby year-level average rose from 42.5% to 50.0%. The corollary alternative conception of impetus-force dissipation or build up appear to be concepts that few Filipino students hold, as indicated by the results for I2, I3, I4, AF5.

An alternative concept which students seem to have trouble overcoming is AR2 (most active agent produces greatest force). From an average of 45.0% during freshmen year, beliefs in this alternative concepts increased to 59.0%, suggesting an incomplete understanding of the nature of force and failure to understand Newton's third law of motion.

On the positive side, significant reductions were found in the alternative conceptions CI4 (circular motion continuance) from 45.0% to 15.4%, G3 (heavier objects fall faster) from 47.5% to 11.5%, and G4 (gravity increases as objects fall) from 60.0& to 19.2%. R2 (weight resists horizontal motion) received a good remediation from a poor 70.0% to a fair 30.8%.

CONCLUSIONS AND RECOMMENDATIONS

In this paper, we studied the conceptual understanding of forces among the undergraduate physics majors of De La Salle University using the Force Concept Inventory. Average test scores varied from 23.0% for freshmen to 39.7% for seniors, indicating a gain of 72.8% over four years of physics education. Although the gain may seem impressive, the fact that the average senior level score is less than twice the chance score is a troubling sign. Of six areas tested, seniors achieved reasonably good understanding in only two areas: falling bodies and inertia. Test scores in Newton's third law and kinematics remained below 40%, while test scores in Newton's second law and force identification stayed near the chance score of 20%.

Improvement in conceptual understanding is most evident after the first introductory-level course in physics where forces are discussed in detail. While the concepts are applied in the succeeding introductory-level physics courses, there appear to be loss of retention in conceptual understanding, suggesting that application especially in the context of problem solving does not necessarily allow retention of conceptual understanding. The dip in average FCI score from sophomore to junior level is a curious result which merit a more thorough study in the future. Intermediate-level physics courses seem to have reinforced conceptual understanding in most areas and enabled the seniors to reach about the same level of conceptual understanding that students fresh from a course dealing with the concept of forces have. Unlike other concepts, increased understanding of falling bodies was more evident from junior to senior year than during the freshman-sophomore interval, suggesting a significant positive impact of intermediate-level courses.

Except for falling bodies and inertia, there is poor retention of the conceptual understanding attained during their first introductory course in physics. This suggests a lack of reinforcements on the concept of forces in the other introductory-level physics courses. Understanding of the second law, or the relationship of forces and motion is particularly alarming since it seems that the physics majors revert to their preconceptions very quickly after instruction and four years of physics education failed to change their conceptions at all. Introductory-level instruction even contributed negatively to student understanding. Such negative findings demand a complete reassessment of teaching strategies for the topic.

On the whole, understanding of the very central physical concept of forces is improved somewhat by four years of study in a physics program. While improvement in average test scores appear high, the fourth-year level of 39.7% is still unacceptably low. This study revealed that except for ideas on falling bodies, improvements in conceptual understanding occur during the first introductory-level course in physics, while intermediate-level physics courses generally help the students retain what they have learned in their first physics course. Enhancement of force concepts seems to be a big problem when physics majors are taking their other introductory-level courses. Improvement in conceptual understanding of forces to acceptable levels lies therefore in (1) improved pedagogy in the introductory-level mechanics course, and (2) strategies to make applications of force concepts a means of enhancing conceptual understanding in other introductory-level courses.

The just-above chance score of 23% among freshmen reveals that in spite of the fact that all Filipino high school graduates took at least one year of physics, Newtonian concept of force appears to have not been accommodated at all in high school. This situation could have stemmed from the fact that around 95% of high school physics teachers in the Philippines have had no formal training in physics at all. But if we consider that students who enter De La Salle University generally come from the better schools in the country where one could expect "qualified" physics teachers, coupled with the result of this study showing senior-level FCI average of 39.7%, could it be that many of the "qualified" physics teachers are non-Newtonian thinkers?

While this initial study was conducted in a single institution in one schoolyear, it has revealed some curious results like the dip in FCI scores from sophomore to junior level, and the consistently low scores of physics majors even after four years of instruction. It will certainly be interesting to know if the same conditions prevail in other institutions.

Appendix. Physics education and educational system at De La Salle University and the Philippines

Pre-university schooling in the Philippines includes six years of elementary and four years of high school. A typical college freshman would have completed ten years of basic education at the age of about 16. This term is two years shorter than what is found in many other countries. While a great majority of Filipino students enter the public school system, most of those who enter De La Salle University come from the private school system, where in some cases, students spend an additional year in elementary school. In addition, these students would have undergone about three years of pre-elementary schooling. All high school graduates of the Philippine system would have taken at least a year of physics as it is a required subject, usually taken during the fourth year of high school. There are however, quite a number of special science high schools where students would have taken physics as a separate subject for two years.

De La Salle University is widely considered as one of the best universities in the Philippines. De La Salle University follows the trimestral schedule, whereby the schoolyear is divided into three trimesters, each lasting for 14 weeks. This schedule is in contrast with most other universities where the schoolyear is divided into two 18-week semesters. Students at De La Salle University are therefore accustomed to a faster pace of course work with a minimal one-week break between trimesters. De La Salle University is one of about eight Philippine universities that offer a Bachelor of Science degree in Physics. The BS-Physics program in the university is an 11-trimester program with a summer spent for practicum work in industry. Calculus is a prerequisite for the introductory-level physics courses, so the majors take their first college physics course in their third trimester of study. They take five college physics courses in all: mechanics, thermodynamics and fluid dynamics, electricity and magnetism, waves and optics, and modern physics, all of which are taken from the third to the sixth trimester of study. The physics majors take two intermediate-level courses each in mechanics, electromagnetism and quantum mechanics, and one course in statistical mechanics during their junior year. Courses in solid-state physics, optics, nuclear and particle physics, and semiconductor physics are taken in their senior year. During their last three trimesters of study, the physics majors work on a project which they eventually present to a panel of three examiners.

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