Diagnosis of Misconceptions about Force and Motion Held by First-Year Post-secondary Students

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Abstract

The present study aims to detect misconceptions in force and motion among Maltese post-secondary students aged 16-17. The revised version of the Force Concept Inventory (FCI) originally designed by Hestenes, D., Wells, M., & Swackhamer, G. (1992) was used. A total of 395 students participated in the study by answering the FCI test at the beginning of their first-year and again at the end of the said year. Data were analysed by using a method used by Martín-Blas, T., Seidel L. & Serrano-Fernández A. (2010). In this study all of the known misconceptions given in the original paper by Hestenes, but modified by Bani-Salameh 2017, were examined. The dominant misconceptions from the students' wrong answers for each of the 30 questions in the FCI were determined. A comparison of the dominant misconceptions held by the cohort studied in the pre- and post-test showed that a number of misconceptions persisted. This study reveals that the impetus, active force and action/reaction pairs misconceptions were the most problematic for the students. Only the pre- and post-test results for all students are reported in this study, leaving gender differences for future work.

Keywords: *Force Concept Inventory, post-secondary, Physics, Maltese, misconceptions*

Introduction

Students' weak performance in physics occurs worldwide as Bani-Salameh (2017b) points out and has been addressed by many researchers. When students start learning physics at post-secondary level, they bring various misconceptions as a result of their experience, intuition and perception of the real world. Halloun and Hestenes (1985) indicate the problem of preconceptions (or misconceptions) that students acquire in their life experience. These preconceptions will interfere into their learning process leading to incorrect conclusions about the behaviour of motion. Their study led the way to the design of the force concept inventory (FCI) intended to be given as a pre- and post-test for the determination of possible gain in clearing misconceptions after a course in mechanics. The FCI has been used worldwide by many physics teachers (Martín-Blas, T., Seidel L. & Serrano-Fernández

A. (2010)) and has been proved to be a valid tool to evaluate both correct and wrong concepts in any given group of students as has been shown by Savinainen and Viiri (2008). The FCI consists of thirty multiple-choice questions with qualitative nature examining simple motion and force concepts. Each question has one correct Newtonian concept and four carefully-written plausible distractors to appeal to students' perception of real-world phenomena. Although a copy of the FCI would have been helpful to the reader, for reasons of copyright it is not included. One may get a copy from the Modelling project (Halloun, I., Hake, R., Mosca, E. & Hestenes, D. (1995)). In order to make teaching more effective, it is imperative to identify students' misconceptions before instruction even starts as noted by Bani-Salameh (2017a). Such identification will help educators to focus their attention on those syllabus areas which need a change in the students' way of thinking.

The authors of the FCI (Hestenes, D., Wells, M., & Swackhamer, G. (1992)) make it clear that this test must never be used to select students for a course but to assess understanding of concepts and to check the effectiveness of different teaching modes and styles. Hestenes, D., Wells, M., & Swackhamer, G. (1992) classify concepts in the FCI into six dimensions, namely Kinematics, First Law, Second Law, Third Law, Superposition Principle and Kinds of Force. They also give a taxonomy of misconceptions grouped into six categories corresponding closely to the six concept dimensions. Bani-Salameh (2017a) modified this taxonomy as shown in Table 1 and is adopted in this study. This taxonomy indicates that when a student gives a wrong answer for item 19 (any distractor A, B, C or D), then distractors B, C or D, correspond to the misconception about 'position-velocity undiscrimination' and the 'velocity-acceleration undiscrimination' for option A. All the options shown in the table belong to the distractors in the FCI.

Table 1 Taxonomy of misconceptions about force and motion after Bani-Salameh [2017a].

Code	Misconception	Inventory item
K1	Position-velocity undiscriminated	19B,C,D
K2	Velocity-acceleration undiscriminated	19A; 20B,C
K3	Nonvectorial velocity composition	9C
K4	Ego-centered reference frame	14A,B
I1	Impetus supplied by 'hit'	5C,D,E; 11B,C; 27D; 30B,D,E
I2	Loss/recovery of original impetus	7D; 8C,E; 21A; 23A,D
I3	Impetus dissipation	12C,D; 13A,B,C; 14E; 23D; 24C,E; 27B
I4	Gradual/delayed impetus build-up	8D; 10B,D; 21D; 23E; 26C; 27E
I5	Circular impetus	5C,D,E; 6A; 7A,D; 18C,D
AF1	Only active agents exert forces	15D; 16D; 17E; 18A; 28B; 30A
AF2	Motion implies active force	5C,D,E; 27A

AF3	No motion implies no force	29E
AF4	Velocity proportional to applied force	22A; 26A
AF5	Acceleration implies increasing force	3B
AF6	Force causes acceleration to terminal velocity	3A; 22D; 26D
AF7	Active force wears out	22C,E
AR1	Greater mass implies greater force	4A,D; 15B; 16B; 28D
AR2	Most active agent produces greatest force	15C; 16C; 28D
CI1	Largest force determines motion	17A,D; 25E
CI2	Force compromise determines motion	6D; 7C; 12A; 14C; 21C
CI3	Last force to act determines motion	8A; 9B; 21B; 23C
CF	Centrifugal force	5E; 6C,D,E; 7C,D,E; 18E
Ob	Obstacles exert no force	4C; 5A; 11A,B; 15E; 16E; 18A; 29A
R1	Mass makes things stop	27A,B
R2	Motion when force overcomes resistance	25A,B,D; 26B
R3	Resistance opposes force/impetus	26B
G1	Air pressure-assisted gravity	3E; 11A; 17D; 29C,D
G2	Gravity intrinsic to mass	3D; 11E; 13E; 29C
G3	Heavier objects fall faster	1A; 2B,D
G4	Gravity increases as objects fall	3B; 13B
G5	Gravity acts after impetus wears down	12D; 13B; 14E

In this study, the FCI was used to identify the dominant misconceptions before and after instruction in mechanics in Maltese post-secondary students. Azzopardi (2016) analysed the correct answers in the same cohort of students in the pre-test. The Hake's normalised gain and possible relationships between different teaching styles and gain were reported by Azzopardi (2017).

Methods

The goal of this study is to investigate the students' dominant misconceptions on admission to a post-secondary institution and those which persisted after their first-year of instruction in mechanics. All students were informed that their participation in the FCI, is voluntary and in no way will it affect their assessment or performance in their course. The FCI took thirty minutes to complete, was administered as a pre-test under the supervision of the lecturers with their respective groups in the beginning of the course (October 2015) and again later at the end of the same scholastic year (May 2016) as a post-test. Students were encouraged to attempt all items and to base their judgement on their opinion, experience, perception and conviction. All the first-year students in the physics department took part, but only those students (N = 395), who participated in both pre- and post-tests, were considered in this study.

The pre- and post-test FCI results were analysed by a method introduced by Martín-Blas, T., Seidel L. & Serrano-Fernández A. (2010) dealing with the dominant incorrect answers for each question as discussed below. SPSS version 24 was used to analyse the data.

Results and discussion

Overview of the correct answers

Before analysing the wrong answers, the overall performance of students in the pre- and post-tests is illustrated by reporting the percentage of students obtaining a certain number of correct questions from the thirty FCI ones. The histogram in Figure 1 indicates similar distributions for both tests ranging from 0 – 20 correct answers out of 30 in the pre- and 1 – 24 in the post-test. The highest pre-test score obtained

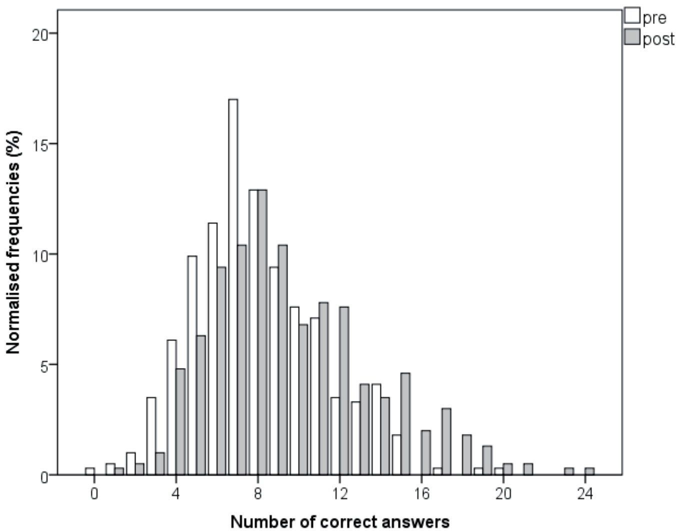

Figure 1 Percentage of students who answered a certain number of the FCI questions correctly.

in this study (20) is higher than that obtained by Bani-Salameh (2017b) which was 14. The reverse applies for the post-test, where in this study the number was 24 and that reported by Bani-Salameh (2017b) was higher. Although the majority of students obtained a similar number of correct answers (8 in pre- and 9 in post-test), a shift to a higher number of correct answers is observed in the post-test indicating an improvement in performance.

The mean percentage score of correct answers per question as shown in Figure 2, (pre-test average score: 26.61% ± 10.43; post-test average score: 32.33% ± 13.42) is very low since the threshold score established by Hestenes, D., Wells, M., & Swackhamer, G. (1992) for Newtonian thinking is 60%. The mean scores obtained in the present study, however, are consistent with research conducted by various authors including Bani-Salameh (2017b) (pre-test average score: 22.3% ± 2.7; post-test average score: 30.4% ± 3.9) and Bayraktar (2009) who reported a mean percentage score of 40.89 ± 12 for Turkish student-teachers.

For analysis purposes, Hake (1998) proposes that the normalised gain ⟨g⟩ is calculated by (%post – %pre)/(100%–%pre) and classifies class averages to have a high-gain if ⟨g⟩ ≥ 0.7, medium-gain if 0.3 ≤ ⟨g⟩ < 0.7 and low-gain if ⟨g⟩ < 0.3. The normalised gain ⟨g⟩ is 0.08 which is low for the students investigated, pointing towards the fact that instruction has made little difference. This value agrees with published data from Bani-Salameh (2017b) (⟨g⟩ = 0.10), but not with Hake (1998) (⟨g⟩ = 0.23 and 0.48 for two different groups).

Figure 2 shows an increase in the percent of correct answers for 24 out of 30 questions in the post-test, two of which show a remarkable increase (***Q7***: 47% to 67% and ***Q12***: 42% to 56%). Five questions out of 30 showed a minor decrease in the

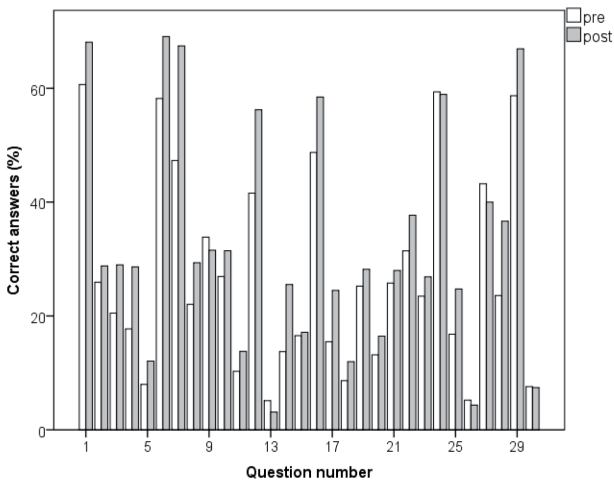

Figure 2 Percentage of correct answers for each question in the FCI for both pre- and post-tests. The mean and standard deviation are 26.61 ± 10.31 for the pre- and 32.33 ± 13.42 for the post-test.

correct answers by around 2%, indicating a negative impact of tutor instructions on students. No change was recorded in ***Q24***, meaning that no improvement occurred.

Analysis of the dominant incorrect answers

The second analysis focused on all incorrect answers for each question of the FCI (both pre- and post-tests) to determine the most dominant and persistent misconceptions. Table 2 describes the misconceptions probed in the items of the FCI along with the percentages of incorrect answers in both pre- and post-tests for that item. The aim of this investigation is to identify misconceptions held by the students and compare them with those found elsewhere. A dominant incorrect answer must have more than 50% of total number of incorrect answers for a specific question. To obtain this percentage, a number of incorrect answers in the FCI which qualify for the same misconception (as per taxonomy shown in Table 1) were added together. For example, in the section 'impetus' (I1), there are 4 questions (5C, D, E; 11B, C; 27D; 30B, D, E) that probe the misconception 'Impetus supplied by hit'. For each question, the number of students selecting those options, were added together and a percentage from the total wrong replies in that question was calculated. Four percentage values are thus obtained but only those greater than or close to 50% (***Q27*** eliminated) were considered as shown in Table 2.

A striking result emerging from Table 2 is the high percentage of students choosing the same wrong answers in many questions, indicating a common way of thinking about force and motion. This result is similar to that found by Bani-Salameh (2017b). The data in Table 2 indicate not only the persistence in the same misconceptions held by students, but also almost with same percentage in pre- and post-tests. The same table also indicates that no dominant misconceptions were held by students in 'centrifugal force' and 'obstacles exert no force'. For the misconceptions 'motion implies active force' and 'Force causes acceleration to terminal velocity', a drop in the dominance level (50%) in the post-test results occurred. For the former, probed by ***Q27***, a drop of 8.7% was recorded while for the latter, probed by ***Q22***, it was 5.5%. It may tentatively be concluded that instruction cleared these misconceptions but one has to be cautious since an element of guessing can contribute to such a result.

In Table 2, the majority of percentages increase in the post-test values indicating that these particular misconceptions have become more dominant. The aim of this study was to identify misconceptions held by post-secondary students and a full list was found as reported in Table 2. The major misconceptions were found in sections 'kinematics: Ego-centred reference frame' (***Q14***: (91.5/90.8), 'impetus: by hit' (***Q5***: 87.4/93.4, ***Q30***: 94.8/97.3), 'impetus: dissipation' (***Q12***: 84.0/90.4; ***Q13***: 96.5/96.1) 'active force: motion implies active force' (***Q5***: 87.4/93.4), 'action/reaction pairs: greater mass implies greater force' (***Q4***: 96.0/93.6) and 'resistance: mass makes things stop' (***Q27***: 89.1/90.8) because the percentage in the post-test remained higher than 90%. This finding is similar to that reported in other countries as indicated by Bani-Salameh (2017a).

Table 2 – Dominant misconceptions with corresponding inventory item and percentages of students who had the particular misconception both in pre- and post-tes

	Misconception	Inventory item (percentage pre/post)
0. Kinematics		
K1	Position-velocity undiscriminated	19(69.6/71.2)
K2	Velocity-acceleration undiscriminated	20(46.8/49.8)
K4	Ego-centered reference frame	14(91.5,90.8)
1. Impetus		
I1	Impetus supplied by 'hit'	5(87.4/93.4), 11(87.0/88.6), 30(94.8,97.3)
I2	Loss/recovery of original impetus	23(53.9/50.7)
I3	Impetus dissipation	12(84.0/90.4), 13(96.5/96.1)
I4	Gradual/delayed impetus build-up	10(54.5/57.9)
I5	Circular impetus	5(87.4/93.4), 6(81.5/72.4), 7(79.5/73.1), 18(60.9/62.9)
2. Active force		
AF2	Motion implies active force	5(87.4/93.4), 27(47.6/38.9)
AF6	Force causes acceleration to terminal velocity	3(49.2/50.4), 22(49.5/44.0)
3. Action/Reaction pairs		
AR1	Greater mass implies greater force	4(96.0/93.6), 28(51.3/60.2)
AR2	Most active agent produces greatest force	15(64.2/74.7), 16(66.3/67.1), 28(51.3/60.2)
4. Concatenation of influence		
CI1	Largest force determines motion	17(80.6/86.0)

CI3	Last force to act determines motion	8(46.9/40.8), 9(49.6/50.4)
5. Other influence on motion		
Resistance		
R1	Mass makes things stop	27(89.1/90.8)
R2	Motion when force overcomes resistance	25(71.6/80.5)
Gravity		
G3	Heavier objects fall faster	2(69.9/80.2)
G4	Gravity increases as objects fall	13(45.9/47.3)
G5	Gravity acts after impetus wears down	13(45.9/47.3)

Conclusions

This study was done to test if dominant misconceptions are present in the students when they answered the FCI questions before starting and after completion of their first year at a post-secondary institution. The analysis of students' results in the FCI, was adopted from Bani-Salameh (2017b). The correct answers for all questions in the FCI were represented as histograms for both pre- and post-tests as a percentage of students obtaining that question correct. From this information, it resulted that the performance was well below the Newtonian thinkers in both pre- and post-tests although performance in the latter was slightly improved. Yet this finding is comparable to other published results. Another histogram shows the percentage of students obtaining a correct answer in each of the thirty questions in the FCI. The second part of this study focused on the dominant misconceptions held by students in both pre- and post-tests. This analysis was based on the counting of the number of incorrect answers for each question. The taxonomy of misconceptions listed in Table 1 was used. The most dominant misconceptions in our study where a percentage of more than 90 was shown in the post-test, were found in 'kinematics: Ego-centred reference frame', 'impetus: by hit', 'impetus: dissipation', 'impetus: circular', 'active force: motion implies active force', 'action/reaction pairs: greater mass implies greater force' and 'resistance: mass makes things stop'.

Acknowledgement

I thank the head of the post-secondary institution for granting permission and making it possible to carry this research. My thanks also extend to the then Subject

Coordinator and staff at the Physics Department who cooperated fully with the administration of the survey as well as the participants.

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Bio-note

Carmel Azzopardi has been teaching physics since 1991 at all levels in various schools. He is the author of the book *Mathematical Requirements for Advanced and Intermediate Level Physics*. He also took part in the making of a TV series entitled *Physics Highway* in collaboration with Mr. J. Bonnici. Carmel Azzopardi is also the creator of a series of videos about physics experiments and demonstrations uploaded on YouTube (www.youtube.com/carmelazzopardi). He presented a paper entitled *The Misconceptions in Mechanics among Students after Completing their Secondary Level Education in Malta* in 'The Future of Education' conference in 2016 and another entitled *The Impact of Teaching Style and FCI Gain on the Performance in Mechanics Test* at the GIREP conference in 2017.