Educational Research (ISSN: 2141-5161) Vol. 1(10) pp. 505-511 November 2010
Available online http://www.interesjournals.org/ER

Full Length Research Paper

The effect of student use of the free-body diagram representation on their performance

Ayesh*[,1], N. Qamhieh[1], N. Tit[1], and F. Abdelfattah[2]

[1]Department of Physics, U.A.E. University, P.O. Box: 17555, Al-Ain, U.A.E
[2]Psychology Departments, King Saud University, Saudi Arabia

Accepted 29 October, 2010

Multiple representations (such as pictures, words, diagrams, and graphs) were found by many researchers in the physics education field to enhance the students' ability to understand the physical concepts. Free–body diagram is a method of the multiple representations and it is defined as the pictorial representation in problems involving forces. In the literature available on physics education, little research has been found concerning the effects of using free–body diagrams on student performance at the college level. The purpose of this investigation is to address and explore the effects of using free–body diagrams on the test results of freshman–engineering students at the university level. This study was conducted using a sample of engineering students taking the introductory–physics course on Newtonian mechanics. The quantitative investigation showed that students who draw correct free–body diagrams while solving a physics problem are likely to solve the problem correctly, while students who draw wrong diagrams are likely to fail in solving the problem. 85% of our students used the free–body diagram representation, although they did not receive any credit for that use, which shows the students' awareness of the importance of the free–body diagram representation.

Keywords: Free–body diagram, physics education, and Newtonian mechanics education

INTRODUCTION

Various studies on physics learning have shown that students who are taught with emphasis mainly on using abstracted formulas fail in school tests, due to the lack of full understanding of physical concepts (Gerace, 2001; Van Heuvelen, 1991a; Van Heuvelen 2001; Heller and Reif, 1984; Gautreau and Novemsky, 1997; De Leone, 2005). Studies also found that the human mind relates best to picture–like representations to better understand the main qualitative features (Kohl et al., 2007; Rosengrant et al., 2009) of a physics problem. Using both methods of physics learning, abstracted formula and picture–like representations, enhances students learning skills and their problem–solving ability in physics (Larkin and Simon,1987; Hestenes et al., 1992; Chi et al., 1981; Larkin et al., 1980; Van Heuvelen 1991b; Van Heuvelen and Zou, 2001).

A free–body diagram is a pictorial representation often used by physicists and engineers to analyze the forces acting on a body. In the preset study, we chose an introductory physics course on Newtonian mechanics offered to freshmen engineering students in United Arab Emirates University (UAEU) which is considered a course that consistently emphasizes the use of free–body diagrams. By analyzing students' performance in the final physics exam, we found that the majority of the students tend to draw their own diagrams in solving exam problems, even when they receive no credit for drawing them. In this study, we focused our attention on the effects of accurate presentations of such diagrams on solving the exam problems correctly. Our goal was to

*Corresponding author E-mail: Ayesh@uaeu.ac.ae

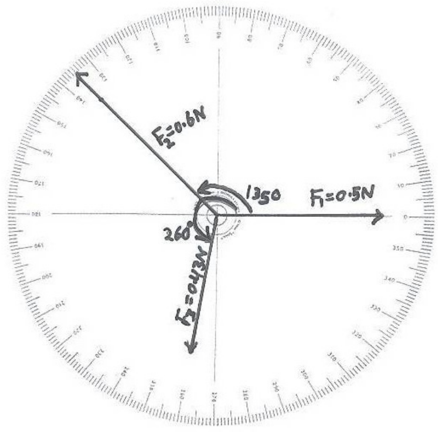


Figure 1: An example from students' laboratory work of the Force Table Experiment on the free–body diagrams.

Problem 2) **(3 points)**

A 10 kg object is released from rest on a rough surface having an inclination of 30°. The coefficient of kinetic friction between the object and the surface is 0.2. Calculate the acceleration of the object.

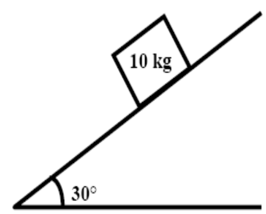


Figure 2. The test problem used in the current investigation

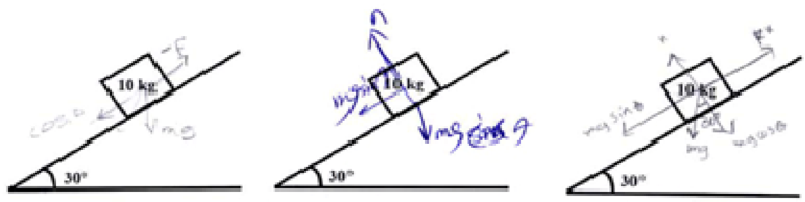
stress the great importance of incorporating the free–body diagram representation for better understanding of the physics concepts which reflect on their performance in the physics course exams.

METHOD

A sample of 254 freshman–engineering students taking the introductory–physics course on Newtonian mechanics at UAEU was included in this study. In teaching this course, instructors used the same calculus–based textbook (Physics for Scientists and Engineers, Serway Jewett, 6th edition) and the same method of instruction over 11 sections. Each section contained 20–25 students where instructors would further elaborate to their students how to use the free–body diagrams, to represent the forces acting on objects and their importance on enhancing understanding of mechanical problems. Also, students activities during the course (problem–solving, assignments, quizzes, and laboratory) were dealt with solving many problems, whereby students needed to draw free–body diagrams in solving problems. For instance, during one laboratory session, students used the Force Table (Pasco ME–9447) to find experimentally a force (F_3) that balances another two forces (F_1 and F_2) acting on the ring in the center of the table. The students then were instructed to draw the free–body diagram of the ring and use it to confirm theoretically their experimental findings. An example from students' work is shown in Figure 1.

To produce a free–body diagram, students were trained during the interactive lectures to: (i) consider all of the forces acting on each object; (ii) make a rough sketch which include the objects of interest in the problem; and (iii) represent all external forces that affect the motion of the objects by using labeled arrows. The feedback was provided orally by the professor during the lecture, while oral and written feedbacks were provided to the students by teaching assistants in the laboratory sessions and also through the graded homework assignments and quizzes.

To collect the data for the present research, one test problem (shown in Figure 2), which is hard to solve without a free–body diagram, was chosen from a final exam. Students were not



Code (1) Code (2) Code (3)

Figure 3. Samples of students' free–body diagrams of each code

Code	Test problem grade (out of 3)	Number of Students	Code	Test problem grade (out of 3)	Number of Students
0	0	28	2	0	24
0	0.5	2	2	0.5	0
0	1.0	2	2	1.0	12
0	1.5	1	2	1.5	3
0	2.0	1	2	2.0	7
0	2.5	0	2	2.5	2
0	3.0	5	2	3.0	27
1	0	41	3	0	4
1	0.5	0	3	0.5	0
1	1.0	6	3	1.0	2
1	1.5	1	3	1.5	1
1	2.0	4	3	2.0	17
1	2.5	0	3	2.5	2
1	3.0	6	3	3.0	56

instructed to draw a free–body diagram; neither received any credit for drawing them. For consistency, one instructor graded the problem out of 3 points for students in all sections. The hard copies of the final exam were collected and used to gather students' free–body diagram information according to the following code: (0) the student did not draw free–body diagram at all on the exam paper; (1) the student drew a free–body diagram that contains major error(s); (2) the student drew a correct free–body diagram that is lacking some information (such as force label); and (3) the student drew a correct free–body diagram with all required labels. Examples from students' work on the codes 1–3 are given in Figure 3.

RESULTS

To investigate the effect of the free–body diagram on students' performance in the test, the results were classified into groups according to (i) the free–body diagram code, and (ii) the student grade (out of 3) in the test problem (Figure 2) of the final exam, as shown in Table 1. The results are then represented in the stacked histogram shown in Figure 4a. The horizontal axis represents the free–body diagram code, while the vertical axis represents the total number of students. The height of each partial "stack" within a column in the histogram corresponds to the number of students with a particular grade between 0.0 and 3.0. The histogram shows that most of the students (28 students) who did not draw the free–body diagram (code 0) score zero in the test problem, 5 students obtained full grade, and very few number of students obtained grades between 0.5 and 2.5 (maximum of 2 students for each stack in the grade range 0.5–2.5). For the wrong free–body diagram (code 1), most of the students had zero in the test problem (41 students), while only few students had grades between 0.5 and 3.0 (maximum of 6 students in each stack). By increasing the code number, the number of students with zero grade decreases and the number of students with full grade increases significantly for students who drew correct but inadequate free–body diagrams (code 2). Eventually for code 3, where students drew correct free–body diagrams, most of the students obtained a full grade, and only 4 few students obtained zero grade in the test problem.

The histogram in Figure 4a shows some trends for the variation of the number of students in each stack with the free–body diagram code. These trends are shown in Figure 4b. The following features can be seen in these figures. (i) For students with a grade of 3.0/3.0: a small number of students did not use free–body diagram or used wrong free body diagrams, while the number of

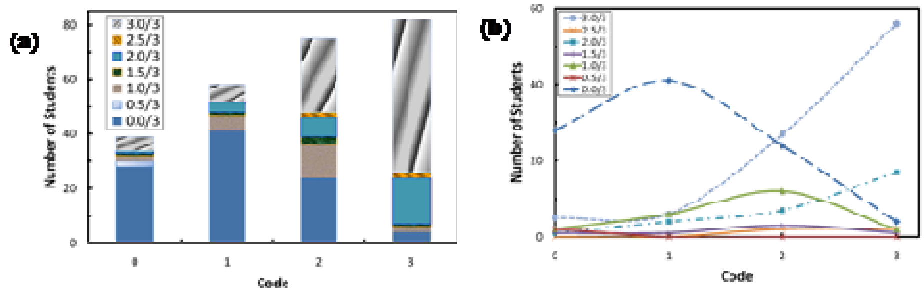


Figure 4. (a) Chart showing the number of students for each free–body diagram code and the grade of the test problem; (b) the variation of the number of students with the free–body diagram code for each grade of the test problem.

Table 2. The categories of students' grades

Grade range	Average grade
Less than 59.5%	F
59.5% – 69.4%	D
69.5% – 79.4%	C
79.5% – 89.4%	B
89.5% – 100%	A

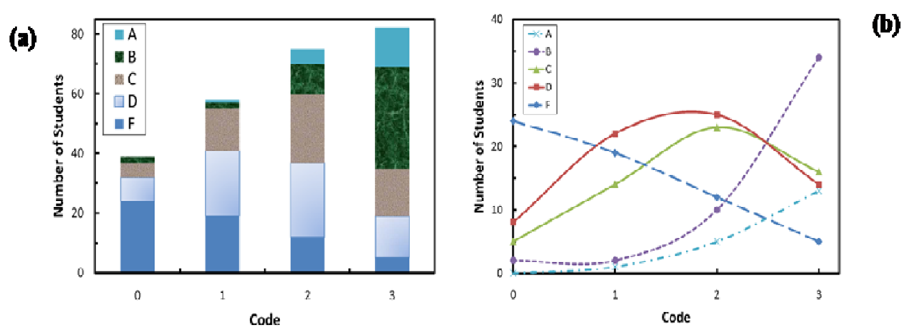


Figure 5. (a) Chart showing the number of students for each free–body diagram code and overall exam's average grade; (b) the variation of the number of students with the free–body diagram code for each overall average grade.

students increased notably for the imperfect (code 2) and for the correct free–body diagrams. It should be noted that the maximum number of students with 3.0/3.0 grade is seen for the category of students with decent free–body diagrams. (ii) For students with a grade 0.0/3.0: their number becomes significant when they did not draw a free–body diagram or they did it with major mistakes (code 0 and 1). However, the number of students' decreases for the incomplete free–body diagram case, and a minimum number of student can be observed for the correct free–body diagram case. (iii) For students with grades between 0.5/3.0 and 2.5/3.0: the number of students is small for most of the free–body diagram codes. Nevertheless, a large number of students with a grade of 2.0/3.0 is observed to draw the correct free–body diagram.

In order to study the overall performance of the students in the course (final grade) and its relationship to the use of free–body diagram representation, we classified students' final grades into categories as shown in Table 2. Figures 5a and 5b show the relation of the numbers of students for each average final grade with the

Table 3. The common mistakes the students did in the free–body diagram

Mistake type	Number of students
Drawing all of the forces but with wrong direction of at least one of the them	26
Wrong vector analysis of the gravitational force	20
Missing the friction force	7
Random mistakes	5

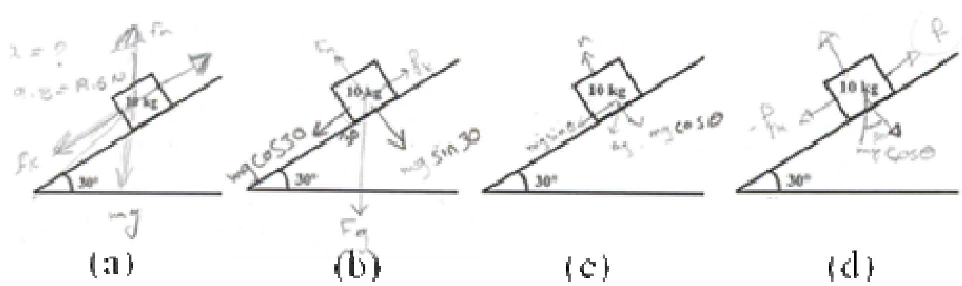


Figure 6. Examples from the students work on the mistakes: (a) wrong direction of at least one of the forces; (b) wrong vector analysis of the force of gravity; (c) missing the friction force; and (d) random mistakes.

free–body diagram code. For each code in the figure, the column contains different stacks that correspond to their average grades. The chart shows that most of the students who did not draw the free–body diagram failed in the course (success grade is 60%). The number of failures decreases for students who drew wrong free body diagram, and the majority of those students had an average grade of 65 (codes 1 and 2). The number of failed students decreases for those drew correct free–body diagrams (codes 2 and 3), and the number of students with average grades of B and A increases significantly for students who drew neat free–body diagrams (code 3). Figure 5b shows a clear trend between the students' final grades and their care or ability in drawing accurate free–body diagrams: the number of failed students decreases with the free body–diagram code.

The wrong free–body diagrams (code 1) were investigated further in order to obtain information about the mistakes students made. The main common mistakes the students made in the free–body diagram were: (i) drawing all the forces but at least one of them has incorrect direction; (ii) wrong vector analysis of the gravitational force (mg); and (iii) missing the friction force. Table 3 shows the number of students who did each of the above mistakes. The rest of the students who drew wrong free–body diagrams did random mistakes. Figure 6 shows some examples from the students' work on each type of mistakes.

DISCUSSION

Using different representations were found to help students construct concepts in physics and problem solving (Kohl, 2007; Van Heuvelen, A. 1991b). Free–body diagram is one type of representations that is import in teaching Newton's laws in the first year of physics courses. The use of free–body diagram representation has a clear impact on the student performance.

During the course, students were engaged in various activities that emphasized the importance of using free–body diagram representation to enhance their understanding of the physical concepts. Although students received no credit on the exam for using the free–body diagram representation, 85% of our students used this representation to solve Newtonian mechanics problems. Among those students 23% constructed wrong free body diagrams, 30% constructed correct but incomplete diagrams, and 32% constructed correct free–body diagrams. This indicates that students were aware of the importance of using the free–body diagram representation in solving the Newtonian mechanics problems.

Our study shows that students who drew correct free–body diagrams are likely to solve the problem correctly, while students who did not draw free–body diagrams or drew wrong ones are unlikely to provide a correct solution to the question. This implies that creating a correct free–body diagram would help students to construct a suitable understanding of the problem which, in turn, would enhance their problem-solving abilities. Our results also show that for students who drew correct but incomplete free–body diagrams, the number of students who solved the test problem correctly is approximately equal to those who failed to solve the question. This implies that the incompleteness of the free–body diagram can reveal the lack of full understanding of physical concepts. On the other hand, students who solved the question correctly by drawing a proper but incomplete free–body diagrams have a better understanding of the problem. They might got the correct answer either accidently or based on memorizing, for instance, the missing forces were irrelevant to the required solution or students have it in mind (without showing it) while solving the problem.

We found that 57% of the students who drew correct and complete free–body diagrams had an overall average grades of B and A, while only 6% of those students failed the course. It points out that outstanding students who perform well in the course are likely to use a neat free-body diagram. On the other hand, this study shows that 62% of the students' who did not draw free–body diagram, failed the course, which implies that students who have poor understanding of the course material are unlikely to draw free body diagrams. The success in drawing and appropriately using these diagrams is correlated to the success of a student in his/here entire course and further it indicates that the concept of drawing free–body diagrams is really fundamental.

The existence of few students who could solve the test problem correctly without drawing the free–body diagram was a noticeable feature that should be considered for a forthcoming research. This feature could be attributed to the fact that students who did not draw free–body diagrams may have done a correct diagram in their minds or they did it on an external scratch paper which were not collected.

The analysis of the students' common mistakes in using free–body diagrams showed that students' mistakes were mainly either drawing one force (or more) in a wrong direction or wrong vector analysis of the gravitational force. This indicates that further emphasis should be considered in the future on: (a) the vector representation on the cartesian coordinates, and (b) the vector analysis of the forces during semester activities such as homework, online quizzes, and projects. Finally, it is recommended that this study will be extended and applied on the coming academic semesters and on various introductory courses.

IMPLICATIONS AND CONCLUSIONS

Our results show that students who draw neat free–body diagram for a particular problem are likely to solve the problem correctly, while students who do not draw a free–body diagram or draw a wrong one are unlikely to solve the problem correctly. The overall course grades show that the B and A level students are likely to draw neat free–body diagrams. Hence, free–body diagram is a fundamental representation that helps students to construct deep understanding for a given mechanics problem. 85% of our students used the free–body diagram representation to help them in solving a Newtonian mechanics problem although they did not receive any credit for that use. This may be taken as an evidence of students' awareness about the importance of the free–body diagram representation to help them to understand and solve Newtonian mechanics problem correctly. Furthermore, students may draw the free–body diagrams because they acquired the habit of using those diagrams in solving the mechanics problems because of the instruction method which engages the students in various activities. In summary, our study showed that the use of the free–body diagram representation during the classroom activities, and instructional laboratory of the first year Newtonian mechanics course helped the students for concept grasping and problem solving effectively.

REFERENCES

Chi M, Feltovich P, Glaser R (1981). Categorization and representation of physics problems by experts and novices. Cogn. Sci. 5:121-5:121-152

De Leone C, Gire E (2005). Is instructional Emphasis on the Use of Non-Mathematical Representations Worth the Effort?. 2005 Physics Education Research Conference Proceedings (AIP, Melville, New York).

Gautreau R, Novemsky L (1997). Concepts first—A small group approach to physics learning. Am. J. Phys. 65:418.

Gerace W (2001). Problem solving and Conceptual Understanding. Proceedings of the 2001 Physics Education Research Conference, AIP, Melville, NY.

Heller J, Reif F (1984). Prescribing effective human problem solving processes: Problem description in physics. Cogn. Instruct. 1:177-1:177-216

Hestenes D, Wells M, Swackhamer G (1992). Force concept inventory. Phys. Teach. 30:141

Kohl P, Rosengrant D, Finkelstein N (2007). Phys. Rev. ST Phys. Educ. Res. 3:010108.

Larkin JH, Simon HA (1987). Why a diagram is sometimes worth ten thousand words.. Cogn. Sci. 11:65

Larkin J, McDermott J, Simon D, Simon H (1980). Expert and novice performance in solving physics problems. Sci. 208:1335

Rosengrant D Van Heuvelen A, Etkina E (2009). Do students use and understand free- body diagrams?. Phys. Rev. ST Phys. Educ. Res. 5:010108.

Van Heuvelen A, Zou, X (2001). Multiple representations of work energy processes. Am. J. Phys. 69:184

Van Heuvelen A (1991a). Overview: case study physics. Am. J. Phys. 59:898

Van Heuvelen A (1991b). Learning to think like a physicist: A review of research-based instructional strategies.. Am. J. Phys. 59:891−897

Van Heuvelen A (2001). Millikan lecture 1999: The workplace, student minds, and physics learning systems. Am. J. Phys. 69:1139-1146