Undergraduate students' difficulties with motion of objects on horizontal and inclined surfaces

Itumeleng Phage
Department of Mathematics, Science and Technology Education,
Central University of Technology, Free State
20 President Brand street, Bloemfontein, 9301, South Africa

Email address: phageh@gmail.com

Abstract. The purpose of this study was to investigate the conceptual knowledge and skills of undergraduate physics students on the motion of two objects on a surface, inclined and or horizontal. The study was conducted with 103 introductory physics students in B.Ed. (FET) Natural Science programme at Central University of Technology, Free State (CUT), Bloemfontein campus. A pre-test was administered to test and investigate their pre-knowledge of concept. The test was on problem-solving on the concept. The results indicated that the majority (more than 80%) of students had huge difficulties with where and how to start in order solve these problems. They lacked basic knowledge of free-body diagram and vector analysis and as resulting, they could not apply or deduce equations to solve. A follow up remedial class was conducted to clear up the confusion and to assist them to acquire necessary and basic skills and knowledge of vector analysis, viz., free-body diagram, finding vertical and horizontal components of vectors, equilibrium conditions as well application of Newton's Second law of motion. With this skill, they were introduced to deriving equations to calculate the acceleration of the objects and the tension of the wire connecting them (mathematical skills). A post-test was thereafter administered and the results indicated a great improvement (more than 70%) in the vector analysis and mathematical application of vectors in problem solving. Follow-up interviews indicated deficiencies and confusion from their previous learning although some students (about 30% of the 70%) indicated they need to be taught the concept first before the test. Their reasoning was they forgot the concept
Keywords: Conceptual knowledge, motion, horizontal and inclined plane, problem solving, free-body diagram, vectors as they didn't understand it previously and or they had previously learnt it to pass before.…

1. Overview

Introductory university physics courses emphasize problem solving (Van Heuvelen, 1991) and students actively construct a knowledge hierarchy on a foundation of qualitative understanding. Physicists often apply mathematical knowledge, but attach physical meaning to mathematical symbols and rules such as numbers, variables and relations (Redish & Gupta, 2009). Mathematical concepts are reinterpreted in the physics context (Meredith & Marrongele, 2008).

Tuminaro and Redish (2004) provided evidence showing that students' inability to transfer their existing mathematics knowledge to physics is the major source of students' errors. Most of the studies were on problem solving (e.g. Freitas et al., 2004; Redish, 2005) or interpretation of specific aspects such as the slope of graphs (e.g. Potgieter et al., 2008; Woolnough, 2000). There are few research studies on students' applications of mathematics knowledge in physics (McBride, 2011; Woolnough, 2000).

One of the fundamental and phenomenal challenges students find is problem-solving which requires undergraduate students analytical and interpretational skills (prior learning, mathematical applications, etc.), (Van Heuvelen, 1991). Studies (Leonard, Gerace and Dufrense, 1999) have reported that even if students succeed in problem-solving, that does not necessarily mean that they have developed a general problem solving skills and or have a thorough understanding or learning of the concept. They further argue that a common misconception of the teachers is that they seem to believe that the more problems students solve, the better their understanding of the concept (an efficient instructional delivery rather than efficient instructional learning).

Leonard et al (1999) emphasize the importance of conceptual analysis of a situation emanating from deep-rooted understanding and proficient ability to solve problems, a cognitive measure. Research (Langbeheim, 2015) has shown that project-based learning promotes student interest in science and improves understanding of scientific content through (a feasible classroom practice, challenging yet fulfilling for both students and teachers), evidence demonstrated from student work. Campbell, 2016 have argued that students believe that they did not learn science best via textbook-based instruction

2. Pedagogical Knowledge on the study of motion on a surface

Many students find it difficult to study science, particularly physics which they find it abstract in nature. One of the fundamental and phenomenal challenges students find is problem-solving which requires undergraduate students analytical and interpretational skills. One concept that requires such skills is motion or not of an object due to impact of force or forces acting on or by such an object.

Physics education research into instruction for introductory university physics courses that emphasize problem solving (Van Heuvelen, 1991) Students actively construct a knowledge hierarchy on a foundation of qualitative understanding.

This paper deals with what skills do first-year undergraduate physics students need to be able to solve problems on motion and its causes of an object. It has been reported that even if students succeed in problem-solving, that does not necessarily mean that they have developed a general problem solving skills and or have a thorough understanding or learning of the concept (Leonard, Gerace and Dufrense, 1999). They further argue that a common misconception of the teachers is that they seem to believe that the more problems students solve, the better their understanding of the concept. This is regarded as efficient instructional delivery rather than efficient instructional learning. Leonard et al (1999) emphasize the importance of conceptual analysis of a situation emanating from deep-rooted understand and proficient ability to solve problems, a cognitive measure.

Research has shown that project-based learning promotes student interest in science and improves understanding of scientific content. Evidence from student work demonstrates that project-based learning is a feasible classroom practice, challenging yet fulfilling for both students and teachers. (Langbeheim, 2015)

Campbell, 2016 have argued that students believe that they did not learn science best via textbook-based instruction. Student knowledge and understanding of force and motion concepts do increase through demonstration as compared to textbook-based instruction.

The study therefore aimed at investigating what difficulties do undergraduate physics students have with motion of objects on inclined and horizontal surfaces.

3. Research questions and objectives

The objective of the study was to determine:

- What background knowledge and difficulties are students encountering with the conceptual analysis of motion on a horizontal and inclined planes?
- If there are any or which effective teaching and learning strategies are required to enhance students' comprehension of conceptual analysis of motion on horizontal and inclined planes.

Other paragraphs are indented

4. Research Methodology

The study was conducted using a mixed method approach, which entailed an opened questionnaire and follow –up interviews with a focus group.

The researcher's journey through this process was also a focus of the study. Initial data were provided by a pretest indicating students' understanding of force and motion concepts. Their subsequent understanding of these concepts and their ability to generalize their understandings, classroom-based assessments, was evaluated via a posttest.

To prepare the students, a revision on kinematics and dynamics was done with them. A questionnaire made of questions (populated from previous exam questions and tutorial exercises) on motion of an object on both horizontal and inclined planes. Follow-up interviews were used to probed students' reasoning behind their solutions. Focus group interviews allowed for the triangulation of pertinent data necessary to draw conclusions from the study.

4.1. Sampling

Participants (available sampling) were comprised of 103 first year undergraduate physics students in the BEd (SP & FET) Natural Science Specialization programme at Central University of Technology, Free State (CUT).

4.2. Data collection

The questionnaire involved ability of students to identify all the forces acting on an object on horizontal and inclined planes and consequently able to represent them fully on a vector diagram. The also had to be able to split a given vector into its vertical and horizontal components.

Derivation of coefficient of friction or equation of friction and any other equation were also expected to be deduced or derived from such a vector diagram. Derivation of equations to be worked with or to assist with problem-solving involved application and use of Newton's Laws of motion especially on the equilibrium or resultant of vectors (forces).

4.2.1. *Object on a horizontal plane.* The Free-body diagram for an object on a horizontal plane showing all the forces acting on an object and its corresponding equations had to be represented as below.

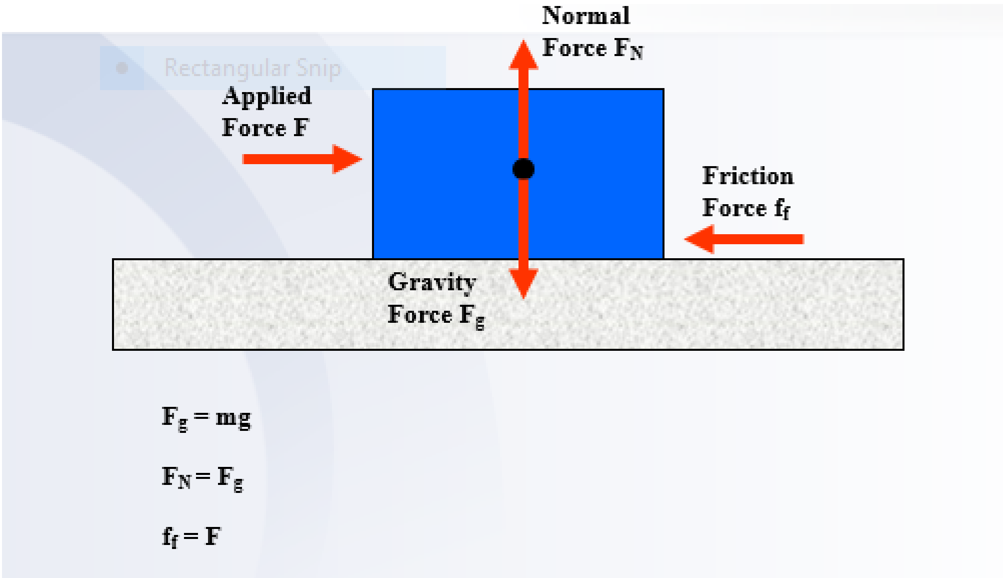


Figure 1. Free Body Diagram.

Respondents also had to state the difference between static and kinetic friction and represents a definition and equation of coefficient of friction.

4.2.1.1. A typical scenario of an inclined was also questioned. Examples of problem-solving exercises and expected solutions

Procedure

- Students have to draw a rough diagram of the problem
- Draw all the forces acting on it
- Use Newton's Laws to deduce equations to solve
- Apply mathematics to solve the equations (simultaneously)

Examples of problem-solving exercises and expected solutions

4.2.1.2. Example 1.1. Examples of problem-solving exercises and expected solutions If the coefficient of kinetic friction between a 35-kg crate and the floor is 0.30, what horizontal force is required to move the crate to the right at a constant speed across the floor?

Solution:

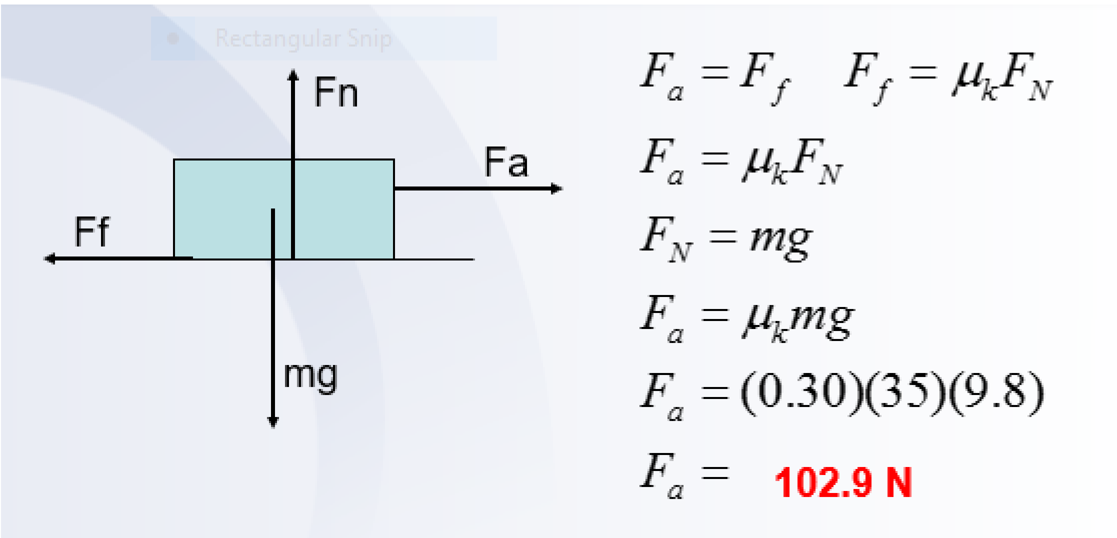


Figure 2. Solution to Example 1.1.

4.2.1.3. Example 1.2. Suppose the same 35 kg crate was accelerating at 0.70 m.s-2. Calculate the applied force. The coefficient of friction is still 0.30.

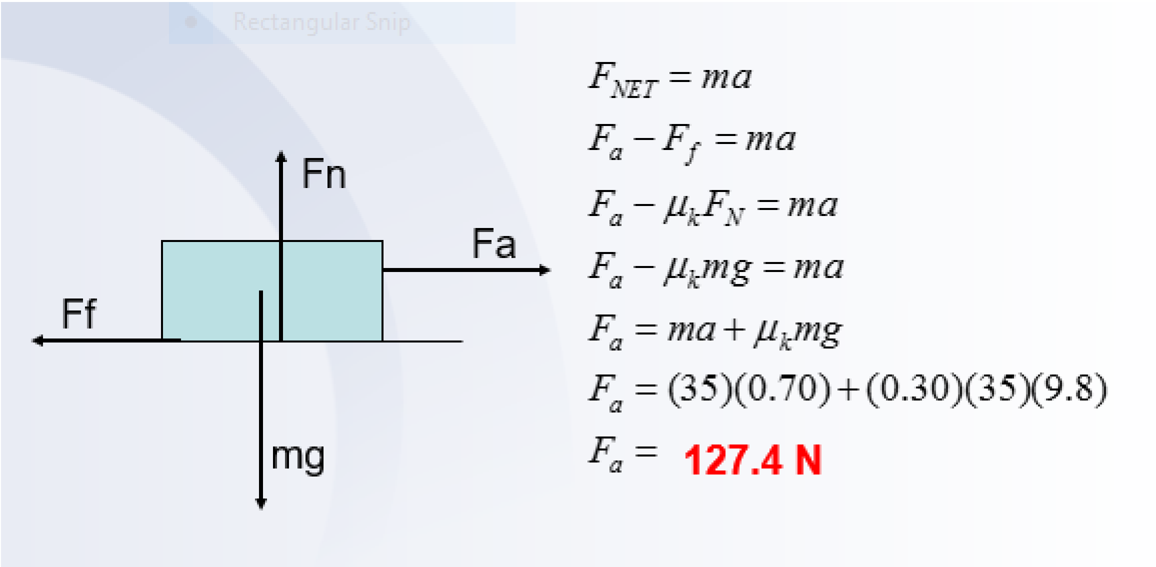


Figure 3. Solution to Example 1.2.

4.2.2. Object on an inclined plane. Examples on an inclined plane involved analysis of problem over and above what they did in solving horizontal plane problem the following:

- First identify the two surfaces, viz., the ground and the incline
- Split weight into its vertical and horizontal components of the incline
- Show mathematically how the angle on the ground is equal to the angle below the incline, made by weight and its weight component

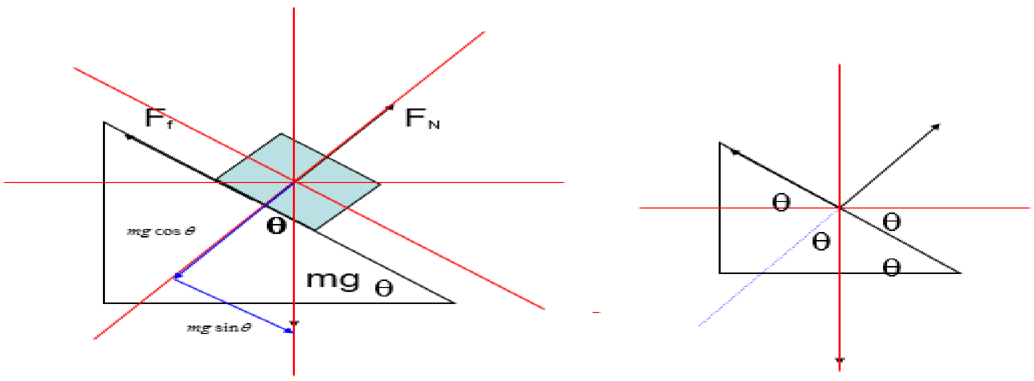
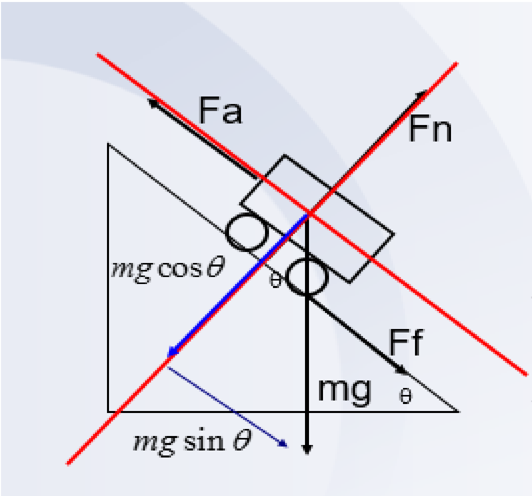


Figure 3. Expected Analysis.

4.2.2.1. Example 2. A person pushes a 30-kg shopping cart up a 100 incline with a force of 85 N. Calculate the coefficient of friction if the cart is pushed at a constant speed.



$$F_a = F_f + mg\sin\theta \quad F_f = \mu_k F_N$$

$$F_a = \mu_k F_N + mg\sin\theta \quad F_N = mg\cos\theta$$

$$F_a = \mu_k mg\cos\theta + mg\sin\theta$$

$$F_a - mg\sin\theta = \mu_k mg\cos\theta$$

$$\mu_k = \frac{F_a - mg\sin\theta}{mg\cos\theta}$$

$$\mu_k = \frac{85-(30)(9.8)(\sin 10)}{(30)(9.8)(\cos 10)} = 0.117$$

Figure 4. Solution to example 2.

5. Results

Table 1. Results obtained.

Task	Problem 1.1	Problem 1.2	Problem 2
Average %	65.3	53.5	40.8
Effect sizes (*w*)	0.58	0.52	≤ 0.24

5.1. Analysis of results

Statistical analysis (descriptive) of results was conducted using effect sizes (w) because of its practical significance of these results, since the study was done with available sampling (Lakens, 2013), i.e., no random sampling was done.

In this study's case comparisons between differences in proportions between conceptual analysis and problem solving successes were interpreted according to Cohen's effect sizes:

$$w = \sqrt{\frac{\chi^2}{n}}$$

The *w*-values are interpreted as follows:

- w<0.3 is a small effect
- 0.3≤w≤0.5 is a medium effect
- w>0.5 is a large effect

5.2 Discussion of results

The effect sizes (w-values) in problems 1.1 was large implying that performance was practical significantly different. This meant that students could remember, comprehend and use conceptual knowledge constructively.

The performances and Problem 1.2 indicated a medium effect, meaning participants answered differently. This implied that students struggled to add and to use knowledge used in solution of problem 1.1. The effect size of the problem 2 was smaller (insignificant), implying students had difficulty with what they have to do and the conceptual understanding. The questions were answered similarly, either both correct or both incorrect, forgetting that they had to find and use weight components.

6. Limitation of study

The study is limited to introductory physics students at Central University of Technology, Free State, therefore no generalised conclusion can be made.

7. Conclusion

In the physics domain, the majority of participants were unable to transfer and integrate their correct conceptual (kinematics and algebraic) knowledge and skills on the representation and analysis/interpretation of motion on horizontal and inclined planes.

Student knowledge and understanding of force and motion concepts do increase through demonstration as compared to textbook-based instruction.

Participants reveal the mathematics knowledge, but lack the necessary physics knowledge and conceptual understanding, e.g. in the kinematics and dynamics (Newton's equations and Laws).

8. References

[1] Arons, A.B., Gould, H. and Gould, M., 1991. A guide to introductory physics teaching. American Journal of Physics, 59(2), pp.189-190

[2] Campbell, M., 2006. The effects of the 5E learning cycle model on students' understanding of force and motion concepts. University of Central Florida, Electronic Theses and Dissertations

[3] Langbeheim, E., 2015. A project-based course on Newton's laws for talented junior high-school students. Physics Education, 50(4), p.410.

[4] Maloney, D.P., 1990. Forces as interactions. The Physics Teacher, 28(6), pp.386-390.

[5] Van Heuvelen, A., 1991. Overview, case study physics. American Journal of Physics, 59(10), pp.898-907.