THE FRICTIONAL FORCE LEARNING MODULE BASED ON HANDS-ON AND INTERACTIVE LECTURE DEMONSTRATION APPROACHES

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THE FRICTIONAL FORCE LEARNING MODULE BASED ON HANDS-ON AND INTERACTIVE LECTURE DEMONSTRATION APPROACHES

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ABSTRACT

The major goal of this research is to construct a frictional force learning module to provide clear understanding on the concepts of frictional force to Thai students in Mathayomsuksa 4 (tenth grade). The study started from the identification of the basic concepts of frictional force. Then, open-ended questions were constructed to survey students' understanding of the concepts of frictional force. The questions were distributed to 241 Thai students. The results revealed these students' misunderstanding regarding the concepts of frictional force, such as the direction of frictional force, the type of frictional force, and the effect factors on the magnitude of sliding frictional force. This evidence led to the construction and development of a frictional force learning module that is composed of a frictional force conceptual survey, lesson plans based on Hands-On and Interactive Lecture Demonstrations (ILDs), demonstration sets of direction, type, and effect factors on magnitude of the sliding frictional force, and worksheets. Ultimately, the learning module was validated and modified by statistical tests, experts' suggestions, and a pilot study with 63 students, in order to reach a statistically reliable instrument.

This learning module was then used with 293 tenth graders. It was evaluated through the students' conceptual understanding and satisfaction questionnaire. The results revealed that the instruction through this frictional force learning module enabled the students to increase their learning moderately, as indicated by the average normalized gain **(<g>**) of 0.61. Moreover, more than 85% of these students agreed that they gained a better understanding of frictional force concepts from this proposed learning module.

KEY WORDS: FRICTIONAL FORCE/ HANDS-ON/ INTERACTIVE LECTURE DEMONSTRATIONS/ NORMALIZED GAIN

141 pages

ชุดการเรียนรู้เรื่องแรงเสียดทานโดยอาศัยการเรียนรู้แบบลงมือทำและการบรรยายประกอบการสาธิตเชิงปฏิสัมพันธ์

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บทคัดย่อ

วัตถุประสงค์ของงานวิจัยนี้คือการสร้างชุดการเรียนการสอนเรื่องแรงเสียดทาน เพื่อเพิ่มความเข้าใจของนักเรียนไทยในระดับมัธยมศึกษาชั้นปีที่สี่ เริ่มต้นจากการศึกษาสาระสำคัญเรื่องแรงเสียดทานในระดับมัธยมศึกษาชั้นปีที่สี่ จากนั้นสร้างคำถามปลายเปิดเพื่อสำรวจความเข้าใจของนักเรียนเกี่ยวกับแนวคิดหลักของแรงเสียดทาน คำถามนี้ใช้เก็บข้อมูลกับนักเรียนจำนวน 241 คน และพบความเข้าใจผิดของนักเรียนไทยในแนวคิดหลักของทิศทางของแรงเสียดทาน ชนิดของแรงเสียดทาน และปัจจัยที่ ส่งผลต่อขนาดของแรงเสียดทานไถล นำข้อมูลดังกล่าวไปใช้ประกอบการสร้างและพัฒนาชุดการเรียนการสอนเรื่องแรงเสียดทานได้แก่ แบบสำรวจความเข้าใจเรื่องแรงเสียดทาน แผนการสอนโดยอาศัยรูปแบบกระบวนการเรียนการสอนแบบลงมือทำ(Hands-On)และการบรรยายประกอบการสาธิตเชิงปฏิสัมพันธ์(ILDs) ชุดสาธิตทิศของแรงเสียดทาน ชุดสาธิตชนิดของแรงเสียดทานและชุดสาธิตปัจจัยที่ส่งผลต่อขนาดของแรงเสียดทาน รวมทั้งใบงานประกอบการเรียนเรื่องแรงเสียดทาน ชุดการเรียนการสอนเหล่านี้ได้รับการประเมินจากทั้งผู้เชี่ยวชาญ และการนำไปทดลองใช้กับนักเรียน 63 คน เพื่อปรับปรุงให้มีประสิทธิภาพมากขึ้น

มีการนำชุดการเรียนการสอนนี้ไปใช้สอนนักเรียนระดับชั้นมัธยมศึกษาปีที่สี่จำนวน 293 คน เพื่อประเมินคุณภาพ จากการ ประเมินความเข้าใจด้านเนื้อหาและความพึงพอใจของนักเรียนต่อชุดการเรียนการสอน พบว่า การสอนโดยใช้ชุด การเรียนการสอนที่สร้างขึ้นนี้ ทำให้นักเรียนมีการเรียนรู้เพิ่มขึ้นในระดับปานกลาง (**<g>** = 0.61) และนักเรียนกว่า 85 เปอร์เซนต์เห็นด้วยว่าชุดการเรียนการสอนนี้ช่วยให้เข้าใจเรื่องแรงเสียดทานเพิ่มขึ้น

141 หน้า

CONTENTS

CONTENTS (cont.)

CONTENTS (cont.)

LIST OF TABLES

LIST OF TABLES (cont.)

Table **Page**

LIST OF TABLES (cont.)

Table **Page**

LIST OF FIGURES

LIST OF FIGURES (cont.)

LIST OF FIGURES (cont.)

CHAPTER I
INTRODUCTION

The dissertation introduction addresses a presentation of an importance for doing this research to promote Thai high school students' understanding of frictional force concepts. After that the purposes of this study, the research questions, and the scope of the research are concisely presented. Finally, we present the summary of the introduction chapter.

1.1 Context of this study

The study of force and motion is a branch of that of classical mechanics. This leads to the study of such topics as gravitation, electricity and magnetism, according to the nature of the forces and motion dealt with. Of course, it is difficult to study such fields of physics without mastering the general laws in force and motion. Thus, it is necessary for students to comprehensively conceive the concepts (Khumaeni et al, 2008). However, Thai high school students have taken less than 35% score of the achievement test for 3 years. This was reported by The National Institute of Educational Testing Service (NIETS). They have analyzed the O-NET data during 2007-2009 and found that Thai students in Matthayomsuksa 6 had the decreasing score from year 2007 to year 2009 in the topic of force and motion. Particularly, in 2009 the achievement in the topic of force and motion was considered as the lowest of all physics topics. These results were from almost 350,000 Thai high school students across Thailand, who took the O-NET exam. They gained the average score 4.19 from the full score 17.50 or 24% (NIETS, 2011). This represents not only the unsuccessful teaching and learning of this topic in high school levels of Thailand, but also displays the low background knowledge of Thai students that they will bring to the university classrooms.

Furthermore, the force and motion consists of several complicated and relevant concepts namely the Newton's first, second and third laws of motion, frictional forces, position, velocity, acceleration, projectile and circular motions, free falling object and others. The review of literature concerning teaching and learning sub-topics of force and motion of Thai researchers disclosed some significant documents. For instance, Panijpan and colleagues (in 2009) presented a magnetic set-up to teach the Newton's laws of motion. The same concept was also reported in the research of Nopparatjamjomras and his colleagues in 2010 by using the mechanic instrument. Moreover, the free falling object concept was studied in the work of Arayathanitkul and his colleagues in 2011. Nevertheless, teaching and learning the frictional force concept of Thai students has been investigated in a small number of studies.

Therefore, in the preliminary work we started to survey a group of Thai high school students (n=46) about the frictional force concepts by using the open-ended questions. All students have learned the frictional force concept prior to the test. We found that almost 80% of these students held the alternative concepts, for example, (1) the direction of frictional force was always opposite to the motion of the object, and (2) when the object moved, the kinetic friction always acted between the contact areas. In addition, our preliminary results were similar to certain significant studies, which clearly revealed that many students were really confused about frictional forces (Paulo & Adriano, 2005; Sharma & Sharma, 2007; Ahmet & Nazmi, 2008).

These preliminary results encouraged the researchers to arrange a more appropriate approach for Thai high school students learn the frictional force. Therefore, we aim to construct the active learning module based on the hands-on and the Interactive Lecture Demonstrations (ILDs) approaches. The students' prior knowledge of frictional forces is utilized as key resources for designing this learning module. Moreover, the learning module will give students an opportunity for doing experiment, discussing with their peers, and constructing their own concepts of frictional forces via the everyday life situations.

1.2 Purposes of the Study

The objectives of this study are:

(1) to investigate the alternative concepts of frictional forces of Thai high school students, and

(2) to improve Thai high school students' understanding of the frictional force under the learning module based on the hands-on and the Interactive Lecture Demonstrations (ILDs) approaches designed by the researchers.

1.3 Research Questions

To achieve the purposes of this study, the research questions will be responded.

(1) What are the alternative concepts of frictional forces held by Thai high school students?

(2) Does the learning module based on the hands-on and the Interactive Lecture Demonstrations (ILDs) approaches designed by the researchers increase high school students' conceptual understanding of frictional forces?

1.4 Research Structure

This dissertation gives research data concerning the teaching and learning of frictional forces of Thai high school students. The study introduces the frictional force learning module based on the hands-on and the Interactive Lecture Demonstrations (ILDs) approaches designed by the researchers. There are seven main chapters in this dissertation.

Chapter I: Introduction—the significance of this research and the aim of the research study.

Chapter II: Literature Review—the key concepts of frictional forces, research of students' alternative concepts of frictional forces, research of the frictional force teaching and learning, the hands-on and the Interactive Lecture Demonstrations (ILDs) approaches, and the normalized gain.

Chapter III: Frictional Force Conceptual Survey— how to construct and evaluate open-ended questions to monitor students' understanding.

Chapter IV: Frictional Force Learning Module—the development of the frictional force learning module.

Chapter V: Results—what we have found in this research.

Chapter VI: Discussion— examine what we found, analyze and compare with other studies.

Chapter VII: Conclusions—the summary of the study and suggestions.

1.5 Summary

This chapter presents the overview of this dissertation. It starts from the significance of doing this research in the part of context of the study. Then the research goals and questions are addressed. The seven main chapters of the dissertation are briefly explained in the last section.

CHAPTER II
LITERATURE REVIEWS

This chapter presents the literatures concerning the frictional force and the associated concepts for designing and evaluating the learning module. It consists of five major topics. Firstly, we briefly summarize the key concepts of frictional forces for Thai high school students. Secondly, the significant previous researches reported alternative concepts of frictional forces are illustrated. Thirdly, we show what other researchers have done for teaching the frictional forces. Fourthly, the active learning strategies used in this research namely the Interactive Lecture Demonstrations (ILDs) and the hands-on method are proposed. Finally, we review the normalized gain as the method for evaluation our frictional force learning module in this research.

2.1 The Key Concepts of Frictional Forces

We name the parallel force with the surface that resists the relative motion of an object when the object surface interacts with its surroundings as "*the frictional force*" (Serway and Jewett, 2010; Halliday et al., 2008). This frictional force is significantly important in people's activities in everyday lives. Unless the frictional forces exist, we cannot walk; run and hold the glass and the car cannot move or stop. Of course, the frictional force has been considered as one of the fundamental physics concepts. In Thailand, according to the Basic Education Core Curriculum B.E. 2551 (A.D. 2008), the frictional force is one topic in the fourth strand called the force and motion of science core concepts. The 5^{th}, 9^{th} and 10^{th} graders are required to learn the frictional force concepts comprising definition of frictional forces, magnitude and direction of frictional forces, types of frictional forces (static and kinetic frictions) by which all focus on the dry friction in macroscopic scales (IPST, 2011).

In general, if the surface of one object comes into contact to the relative motion with the surface of another object, the frictional force exists, by which the nature of frictional forces is a very complex phenomenon which cannot be represented by a simple model.

However, for high school students, the basic assumptions of frictional forces are required. Ordinarily, the frictional force is proportional to the texture of both surfaces (represented by the coefficient of friction) and the normal force. With the same coefficient of friction, the magnitude of frictional forces depends upon the normal force. Moreover, it is independent of the area of contact and the velocity of motion. These assumptions exclude in the cases of a very small area digging into another surface and the high velocity of motion influenced by the air friction.

Only two types of dry friction, static and kinetic frictions, are considered mainly for high school students. The static frictional force *(f_s)* is the force resists the relative motion of two contacted surfaces of the solid bodies that are not moving on each other. The magnitude of static frictional force (f_s) is equal or less than the resultant of the coefficient of static friction (μ_s) multiplied by that of the normal force (*N*) (i.e. $f_s \leq \mu_s N$). The kinetic frictional force ***(f_k)*** is the force resists the relative motion of two contacted surfaces of the solid bodies that are sliding on each other. The magnitude of kinetic frictional force (f_k) is the resultant of the coefficient of kinetic friction (μ_k) multiplied by that of the normal force (*N*)

(i.e. $f_k = \mu_k N$).The coefficient of kinetic friction is commonly less than the coefficient of static friction. The maximum friction force of two surfaces before the sliding starts is the product of the coefficient of static friction and the magnitude of the normal force, and often called the maximum static frictional force ($f_{s(\max)}$).

The difference between static and kinetic frictional forces can be expressed by the following graph (Figure 2.1). Generally, this graph is plotted from a simple experiment, for example, we gently push (the applied force) a book rested on a table to move. While the book still rests on the table, the static frictional force occurs and linearly grows matching the applied force. Immediately, the book moves (showed by the threshold point). The static frictional force is dropped and changed to the kinetic frictional force. The kinetic friction is approximately constant. The condition that the static friction is greater than the kinetic friction is illustrated by the area beneath the curve (showed by the gray area).

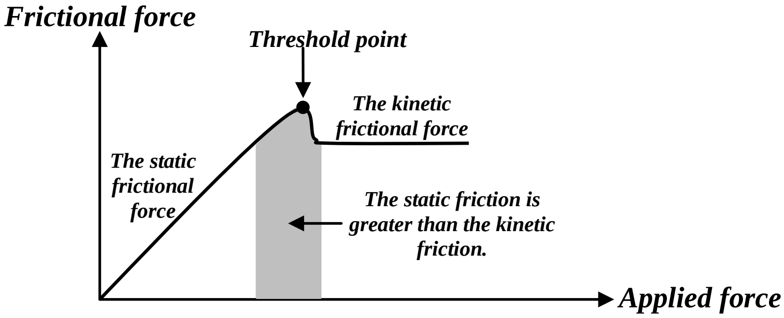


Figure 2.1: The frictional force graph

2.2 Research of Alternative Concepts of Frictional Forces

The previous researches clearly revealed that students were confused about the frictional forces in many real-life situations. Here are some of the alternative concepts of frictional forces.

In 1990, Salazar and colleagues reviewed the physics education researches and presented an alternative concept about the frictional force that many students believed. That was the frictional force is always opposed to the motion of the object. This was strongly agreed with the report of Lee in 1999. Lee found that most students in his research believed that a frictional force is always opposite with the motion. He mentioned that this notion has been deeply embedded in several students due to the way teachers taught the frictional force subject. As well, he suggested that instructors should more concentrate on applying the free-body diagram to analysis the frictional forces on a rigid body in many situations, such as rectangular block sliding down a slope under its own weight, and a disk rolling without sliding on a rough surface acted upon by a force.

Similarly, in 2005, Carvalho and Sousa used basic concept questions of the frictional force with 15 senior students of physics education and school physics teachers for surveying their understanding in this topic. They found that most of participants have misunderstandings about the frictional force in many aspects such as

(1) the frictional force is resistant to motion, (2) frictional forces are always opposite to the direction of the motion, and (3) kinetic friction and rolling friction are the same. In 2010, Prasitpong and colleagues have also found that students usually believed the frictional force opposes the motion of a moving object. Their results were from high school students in Thailand. Moreover, in 2007 Besson and others have addressed the student alternative concepts about frictional force in their literature reviewing; for example, most students believed that frictional force is opposed to the actual motion and not to the relative motion between two solids in contact. Generally, students believed that the frictional force acts only on the upper object, in the case of two objects, one put on top of the other, and an external force applied to the upper one. For the vertical motion, such as when an object is in contact with a vertical surface, many students believed that there is only one frictional force acts on the object in motion.

With its nature, frictional forces are complex and depend on the contexts. Unless students understand the keys concepts of frictional forces, they are rare to catch up the other contexts. This was supported by the research of Trumper and Gorsky in 1997. They conducted the research about frictional force with 180 biology students training for high school teacher in the largest college in Israel. They found the incorrect views such as (1) friction related only to moving objects, and (2) some students were uncertain about the status of friction as a force. Moreover, in 1991 Chia has surveyed 42 university physics students about frictional forces by using interview and open-ended questions. These students have passed at least the first year university physics course. He found that more than 50 percent of these students responded the incorrect ideas in several contexts. For example, these students believed that when a body remains at rest, frictional force always acts on the body. They believed that when an object remains at rest though there is external force acting on it; the frictional force acting on the object is always equal to zero. When a man is walking forward, frictional force acting on the man by the floor always points the backward direction. When a man is pedaling a bicycle, the frictional force acting on the rear wheel of the bicycle is along the backward direction. Moreover, these students believed that when the rider turns his bicycle at the corner of the road, the frictional force acting on the front wheel is in the outward direction. This misconception came from the incorrect idea of the centrifugal force acting on the front and the rear wheel of the bicycle.

Furthermore, some reports found that students usually held the alternative concepts dealing with the static and kinetic friction. For instance, in 2008 Singh explored almost 300 students in nine college calculus-based introductory physics courses about frictional forces by using the open-ended questions. The result presented that many students believed that (1) the static friction is always at the maximum value, (2) the kinetic friction is responsible for keeping the car at rest on an incline, and (3) the existence or nonexistence of friction must affect the work done by you even if you apply the same force over the same distance. In 1999, Morrow and Jackson presented that while teaching non-science majors students they found the alternative concept of frictional force that many students believed that for a couple objects, kinetic friction does not depend only on the normal force; it may be changed from other parameters such as pressure.

Other basic ideas of frictional forces that students have less understanding were such as the direction and magnitude of frictional forces. These were revealed by the research of Self and colleagues in 2008. They reported a misconception in frictional forces held by engineering students that some students believed the direction of the frictional force on a rolling rigid body is irrelevant to the direction of rolling. In the same year, Hancer and Durkan found that almost 80 percent of the students believed that the magnitude of the frictional force depends on the apparent contact areas. This was a result from utilizing the Force and Movement Concept Test (FMCT) to examine the 7^{th} and 8^{th} graders understanding in two schools in Turkey. Additionally, in 2007 Sharma and Sharma probed students’ understanding of frictional force by using their own frictional force conceptual inventory (FFCI). The 177 samples in their study consisted of high school students, undergraduates, physics graduates, and pre-service teacher education students. They found that more than 50 percent of these students have misunderstandings about frictional force involving the coefficient, direction and application of frictional forces. For example, these students believed that the coefficient of frictional force was dependent of area of surface in contact. Frictional force was independent of the direction of the applied force.

Collectively, table 2.1 summarizes these alternative concepts of frictional forces based on their key ideas.

Table 2.1: Alternative concepts of frictional forces and the references

Alternative Concepts	References
Magnitude of Frictional Force	
The magnitude of the frictional force depends on the apparent contact areas.	Hancer & Durkan, 2008
The coefficient of frictional force was dependent of area of surface in contact.	Sharma & Sharma, 2007
***Directions of Frictional Force*s**	
The direction of the frictional force on a rolling rigid body is irrelevant to the direction of rolling.	Self et al., 2008
Frictional forces are always opposite to the direction of the motion.	Carvalho & Sousa, 2005; Salazar et al., 1990; Lee, 1999; Besson et al., 2007; Prasitpong et al., 2010
Frictional force was independent of the direction of the applied force.	Sharma & Sharma, 2007
Static/ Kinetic Friction	
Kinetic friction and rolling friction are the same.	Carvalho & Sousa, 2005
Kinetic friction does not depend only on the normal force; it may be changed from other parameters such as pressure.	Morrow & Jackson, 1999
The static friction is always at the maximum value.	Singh, 2008
The kinetic friction is responsible for keeping the car at rest on an incline.	Singh, 2008
The existence or nonexistence of friction must affect the work done by you even if you apply the same force over the same distance.	Singh, 2008

Alternative Concepts	References
Others	
The frictional force acts only on the upper object, in the case of two objects, one put on top of the other, and an external force applied to the upper one.	Besson et al., 2007
For the vertical motion, such as when an object is in contact with a vertical surface, there is only one frictional force acts on the object in motion.	Besson et al., 2007
Friction related only to moving objects.	Trumper & Gorsky, 1997
It is uncertain about the status of friction as a force.	Trumper & Gorsky, 1997

2.3 Research of Frictional Force Teaching and Learning

The effective teaching tools or processes for frictional forces have been proposed by various educators. Here are some examples.

In 1990, Salazar and others suggested two examples of problem-solving, which could be used to demonstrate that the frictional force acts in the same direction as the center of mass velocity of the body accelerating it. The first example showed the sliding motion of two blocks, one on the top of the other, on a frictionless horizontal surface, when a horizontal force is applied to the lower one. The second example involved a rotational motion or rolling without slipping. They reported that these examples could solve the misconception that the frictional force was always opposed to the motion found in physics classroom. Dealing with the problem solving, in 2001 Leonard introduced a simple way to solve the question involving frictional force concept about finding the smallest angle for a man, who is pulling a box on the ground. His idea focused on the free-body diagram or the normal, static friction and tension acting on the box.

Additionally, in 2008 Singh used the isomorphic problem pairs (IPPs), which involved the problem solving for several contexts with the same physics principle, with almost 300 introductory physics students in mechanics classes. He showed that when conceptual and quantitative questions, which were set up as pairs, were given. Students, who answered both questions in the IPPs often outperformed on the conceptual questions more than those who answered the corresponding conceptual questions only. However, this teaching process, IPPs, displayed low effective in the frictional force concept. He suggested that friction was so strongly and automatically triggered by the context, which students were hard to look for analogy with paired problems.

Not only the problem solving, but also the experiments were suggested for teaching and learning the frictional force concept. For instance, in 1999 Morrow and Jackson designed the experiment to demonstrate that kinetic friction is constant and depends only on the normal force. The experimental setup consists of the motion and force sensor, wood block, 2 kg mass, and hanging mass/pulley system, which all are put on the table. The motion sensor measured the position of the object, the force sensor measured the applied force acted by the hanging mass/pulley system to the object. The software shows velocity-time, velocity-distance, force-time, frictional force-applied force, and frictional force-velocity. Similarly, in 2002 Takahashi introduced a friction experiment based on the force sensor of the commercial software. It displayed the characteristics of static and kinetic frictions. The force sensor was attached to the plane along which the block moved. The beaker of sand was slowly poured into the hanging bucket for pulling the block to move. A computer graphed the force sensor reading as a function of time. Moreover, in 2005 Carvalho and Sousa set up the non-expensive laboratory equipment for frictional forces. This apparatus was used to find the coefficient of friction, both static and kinetic, with rolling objects. In the experiment, they let the solid cylinder roll down freely on the flat inclined surface, measured the distance between the marks (by ink) on the surface, and repeated this procedure for different angles.

In 2007 Heavers suggested an inquiry-based activity for the friction force. It demonstrated the coefficient of kinetic friction by graphing the frictional force versus normal force for a wooden block and calculator cover, which were released to slide on the inclined wooden plane. This activity could also help students to reinforce the idea that the frictional force does not depend on the area of the surface in contact, by working with the wooden block on its wide side and then on its narrow side.

In the same year, Besson and colleagues proposed a useful way to teach friction in high school and college levels. They designed a sequence of teaching process based on the student misconceptions. They suggested that 5 parts of the sequences of topics in class include (1) the introduction of the importance of friction in everyday life, (2) vertical frictional force, (3) static and kinetic friction, (4) topography of surface and mechanisms producing friction, and (5) frictional force from the energy point of view. In each step they introduced both demonstrations and hands-on activities. This method discovered the positive results after testing with groups of high school students and teachers. Furthermore, the virtual model called rubber-band model was proposed by Reichert in 2001 for explaining the frictional force. Instructors could draw the model to visualize the chemical bond of the two contacted objects, which applied the frictional force on each other.

In addition, there were many works addressing the ideas about the frictional force in rolling motion. For examples, Pinto and Fiolhais (2001) considered rolling with and without slipping of a cylinder on a horizontal plane, acted upon by a constant horizontal force. They found that if a body had no rotating motion, the study of its motion could reduce to the study of its centre-of mass motion. In contrast for the rotation, the analysis of the frictional force requires a detailed knowledge of the motion of the particles where the frictional forces were applied. Carnero and other (1993) reported the fact that the frictional forces did not work when a body rolls without slipping. Moreover, Basta and other (1999) suggested a simple desktop apparatus online with a PC for studying the rolling motion of the sphere with and without slipping. They used this set up in a physics laboratory for university levels and found that this interactive experiment would promote more student understanding of frictional force.

2.4 Active Learning Strategies

From the constructivist learning theory studying about how students learn, learning is active and is the interaction of the ideas and process. The new ideas of learning come from the re-organized old ideas following the process. Learning is enhanced by the contexts that students find familiar and meaningful. Students (individually or socially) learn or construct own understanding and knowledge of the world via their prior knowledge. Clearly, it means that knowledge cannot be taught, but constructed (Bransford et al., 1999; Bybee, 2002; Kim, 2005).

The major role of instructors based on the constructivism is as the facilitators. The suggestions for learning with the constructivist learning theory are that the students' prior knowledge and the interactive and social learning process are required in classrooms. Moreover, in 1969 the National Training Laboratories (Bethel Maine) produced the Learning Pyramid, modified from the Dale' cone in 1954, which illustrates that if teachers use more active instructions in classes, their students gain more understanding of such subject matters (Lalley & Miller, 2007) (Figure 2.2). The Learning Pyramid represents the average retention rates for different instructional methods. Lecture was found to provide the least retention (5%), and the active methods such as practice by doing and teaching each other were found to provide the most retention (75-90%).

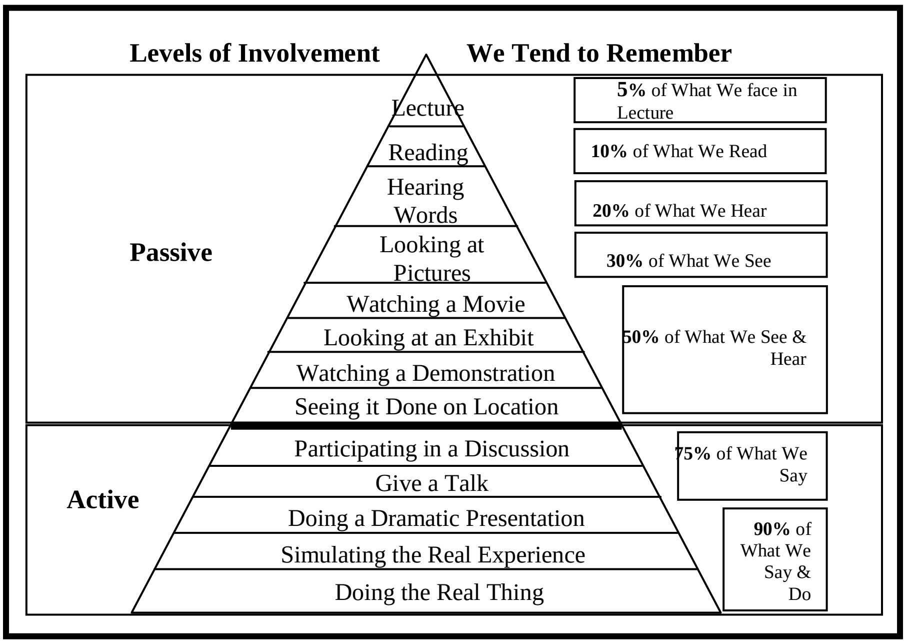


Figure 2.2: The Learning Pyramid (Lalley & Miller, 2007)

Active learning involves providing chances for students to significantly talk and listen, write, read, and reflect on the ideas and concerns of an academic subject (Meyers & Jones, 1993). It refers to the instructional techniques, where the students do more than just listen to or watch the lecturing of the teachers in the classrooms. Moreover, Meyers and Jones (1993) indicated that there are four basic components of the active learning strategies. These four elements are: (1) talking and listening, (2) Reading, (3) writing and (4) reflecting.

The active learning strategies based on the constructivist learning theory used in this research are the Interactive Lecture Demonstrations (ILDs) and the hands-on approaches.

2.4.1 Interactive Lecture Demonstrations (ILDs)

The Interactive Lecture Demonstrations (ILDs) approach is one of the well-known instructional strategies in physics education research designed to enhance conceptual learning in large (and small) lectures through active engagement of students in the learning process. Many real-time physics demonstrations are shown to students following up with making predictions of students about the outcomes on a prediction sheet, and discussing with their friends in small groups. Students then observe the results of the real demonstration, compare these results with their predictions, and attempt to explain the observed phenomena.

The ILDs method was proposed by Sokoloff and Thornton in 1997 with the effort to increase more chances of discussion of students in the large lectures, in particular. There are 8 main steps of the ILDs procedures, which are;

(1) Instructor describes the demonstration sets.

(2) Students note their names and individual prediction on a prediction sheet.

(3) Students discuss in a small group.

(4) Students note the final prediction on the prediction sheet.

(5) Instructor extracts the common student ideas and shows in the whole class.

(6) Instructor and students displays the demonstration.

(7) A few students explain the results, discuss each other and fill out in the result sheet.

(8) Instructor discusses other situations in the same concept.

ILDs have been applied to many physics classrooms worldwide. All revealed the positive results (Loverude, 2009; Thornton & Sokoloff, 1998; Semper et al., 1982). Furthermore, in 2004, Crouch and colleagues have supported that the prediction step in the ILDs facilitates students learning. Learning is enhanced, however, by increasing student engagement through the observation, prediction and discussion.

2.4.2 Hands-On Method

A hands-on method supports students to learn by doing experiments. It requires students to become active participants instead of passive learners. Hands-on science is defined as any science activity that allows the student to handle, manipulate or observe a scientific process (Flick, 1993; Lumpe & Oliver, 1991; Franklin & Peat 2005). Hands-on approach consists of 3 parts: inquiry, structure and experiment. Inquiry refers to the making discoveries for activities of students. Structure refers to the amount of guidance given to students. Experiment refers to the doing experiment for discovering of students. These three components are properly combined each other. Recently, a new term has been proposed for hands-on science called Hands-on/Minds-on science (Lumpe & Oliver, 1991). School science education first proposed the hands-on in the eighteenth century (Craig, 1957). This approach displayed the positive outcomes reported by many researches (Middleton, 1995; Renner et al., 1985; Holstermann et al., 2010).

2.5 The Normalized Gain

The normalized gain is an analytical method used to assess students' learning gain proposed by Richard Hake in 1998. The main concept of the normalized gain concerns the comparison of the difference between pre-test and post-test scores to maximum possible gain. This method differs from general assessment methods such as t-test and z-test. In general, t-test (or z-test) shows only the significant difference between pre- and post-test scores. However, the normalized gain shows the learning gain caused from the learning method used in the classroom. An average normalized gain (<g>) for a course is the ratio of the actual average gain (<G>) to the maximum possible average gain (<G>max), which can be written as

$$<g> = \%<G> / \% <G>max$$
$$= (\%<post> – \%<pre>) /(100 – \%<pre>)$$

when <post> and <pre> are the final and initial class averages.

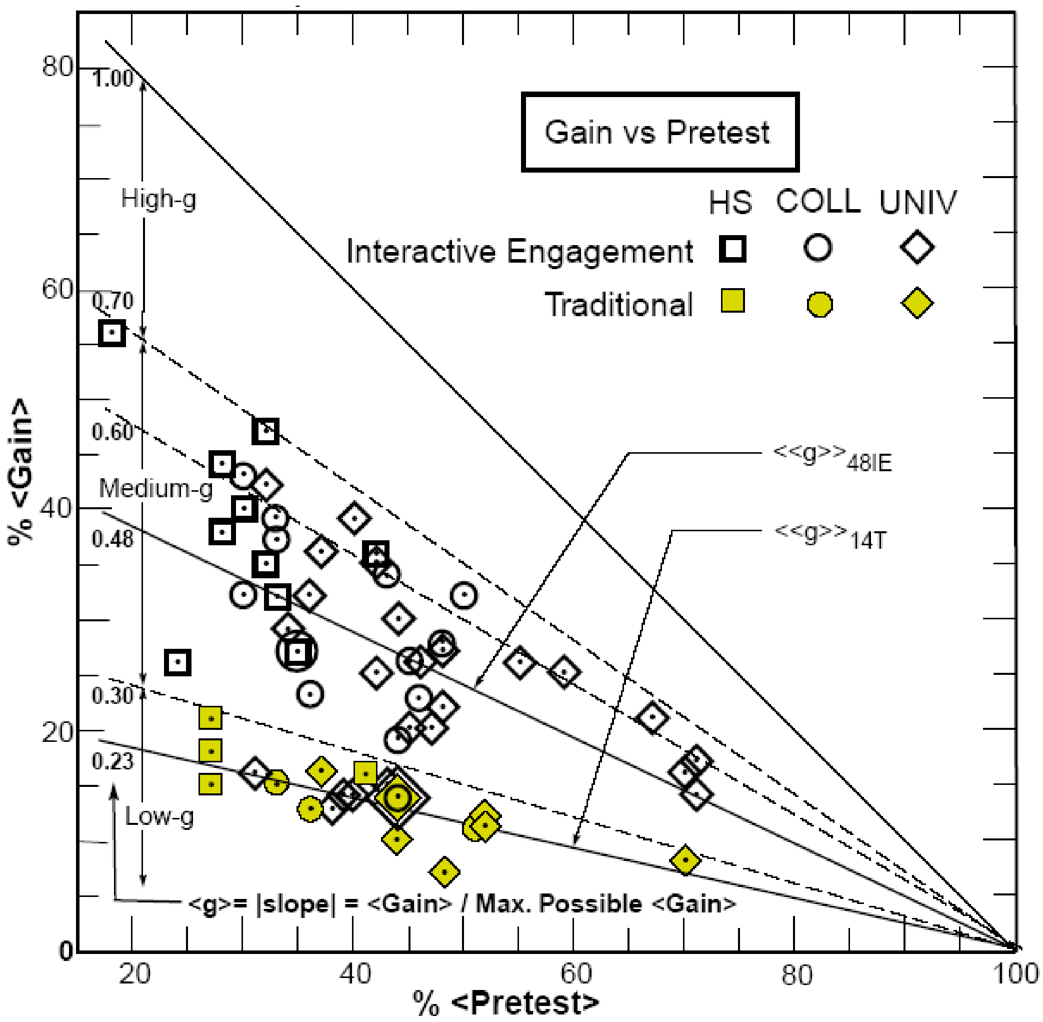


Figure 2.3: %<Gain> versus %<Pre-test> score on the conceptual mechanics diagnostic test called the Force Concept Inventory (Hake, 1998)

In 1998, Hake has reported the levels of the average normalized gains, which are the standard values for traditional courses and interactive engagement courses. He analyzed the pre-and post-test data from 62 introductory physics courses enrolling a total number of students N = 6,542 by using the Halloun-Hestenes Mechanics Diagnostic test or more recent Force Concept Inventory (FCI). He found the average normalized gain 0.23 ± 0.04 for the traditional courses, and 0.48 ± 0.14 for the interactive engagement courses (Figure 2.3). Based on the study, Hake divided the gain values into 3 categories: (1) “High Gain” as <g> greater than 0.7, (2) “Medium Gain” as <g> between 0.3 and 0.7, and (3) “Low Gain” as <g> lower than 0.3.

The graph in Figure 2.3 illustrates the raw data (N=6,542) which Hake used to calculate the 3 levels of normalized gain. There were 14 traditional (T) courses (N =2,084) which made little or no use of interactive engagement (IE) methods, and 48 IE courses (N = 4,458) which made considerable use of IE methods. The participants were high school (HS), college (COLL), and university (UNIV) students. Slope lines for the average of 14_T courses and 48_{IE} courses were shown as <<g>>14_T and <<g>>48_{IE}, respectively.

However, the normalized gain was revised by Marx and Cummings in 2007 for the case that the post-test score was less than the pre-test score. It was named as “**normalized change (*c*)**”. Moreover, Marx and Cummings explained the limitations of the normalized gain that (1) it has a low test-score bias, (2) the normalized gain equation generates a non-symmetric range of scores which makes interpretation difficult in some cases, and (3) if a student achieves a perfect pre-test score (the maximum scores), then the equation yields g = ∞ for any post-test score. The normalized change can be found by using the following equations.

Table 2.2: The conditions and equations of the normalized change

Conditions	Equations of the normalized change (c)
(1) post > pre	c = (post-pre)/(100-pre)
(2) post = pre	c = 0
(3) post = pre = 100 or 0	Drop
(4) post < pre	c = (post-pre)/pre

In this research, since there is no result that the post-test score is less than the pre-test score, the significant statistical method, normalized gain, is used to evaluate the students conceptual understanding of frictional forces before and after the instruction by using the learning module designed by the researchers.

CHAPTER III
FRICTIONAL FORCE CONCEPTUAL SURVEY

This chapter presents how to construct and evaluate the conceptual survey concerning the frictional force concepts created by the researchers hereinafter called "**Frictional Force Conceptual Survey: FFCS**". The conceptual survey was prepared based on two objectives: 1) to investigate the alternative concepts from participated Thai high school students, in order to use as the key resource for designing the frictional force learning module in this research and 2) to assess the learning module which improves the students conceptual understanding of frictional forces. There are 3 main steps in the development of the FFCS as shown in Figure 3.1.

Step I: Extracting the core concepts of frictional forces provided for Thai high school students from the Basic Education Core Curriculum B.E. 2551 (A.D. 2008) of Thailand.

Step II: Creating the open-ended questions as the FFCS, based on the curriculum, the preliminary results and the literature.

Step III: Modifying and evaluating the efficiency of the FFCS by using statistics; the content validity, the item difficulty, the item discrimination and the KR-21reliability.

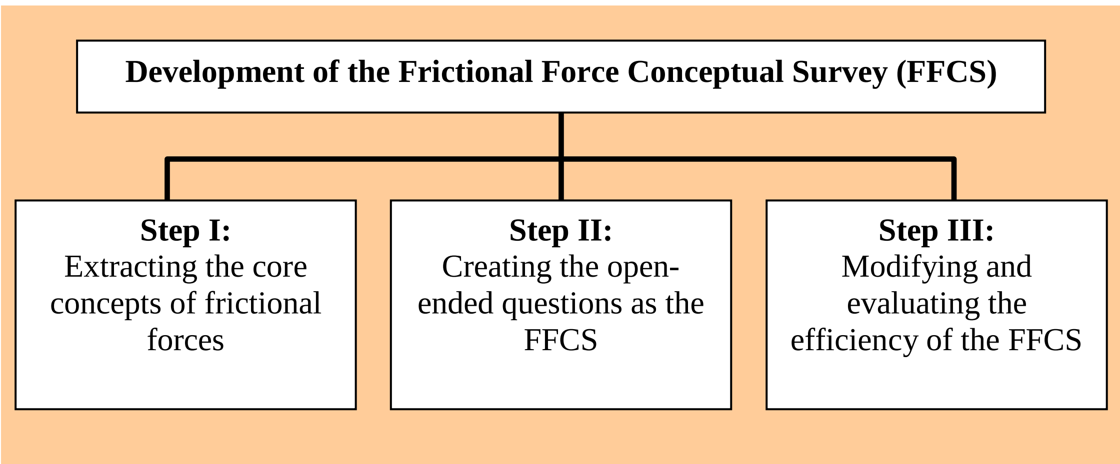


Figure 3.1: Three main steps in the development of the FFCS

3.1 Step I: Extracting the Core Concepts of Frictional Forces

This section shows the core concepts of frictional forces that Thai high school students have to learn. These concepts comply with the Basic Education Core Curriculum B.E. 2551 (A.D. 2008) of Thailand (IPST, 2008). As mentioned in the last chapter, the nature of frictional forces is a very complex phenomenon which cannot be represented by a simple model. On the other hand, for high school students, the basic assumptions of frictional forces are required. Overall, in this level the curriculum focuses on the dry frictional force in the macroscopic scale comprising its definition, properties and types. The frictional force core concepts are displayed in the following Figure.

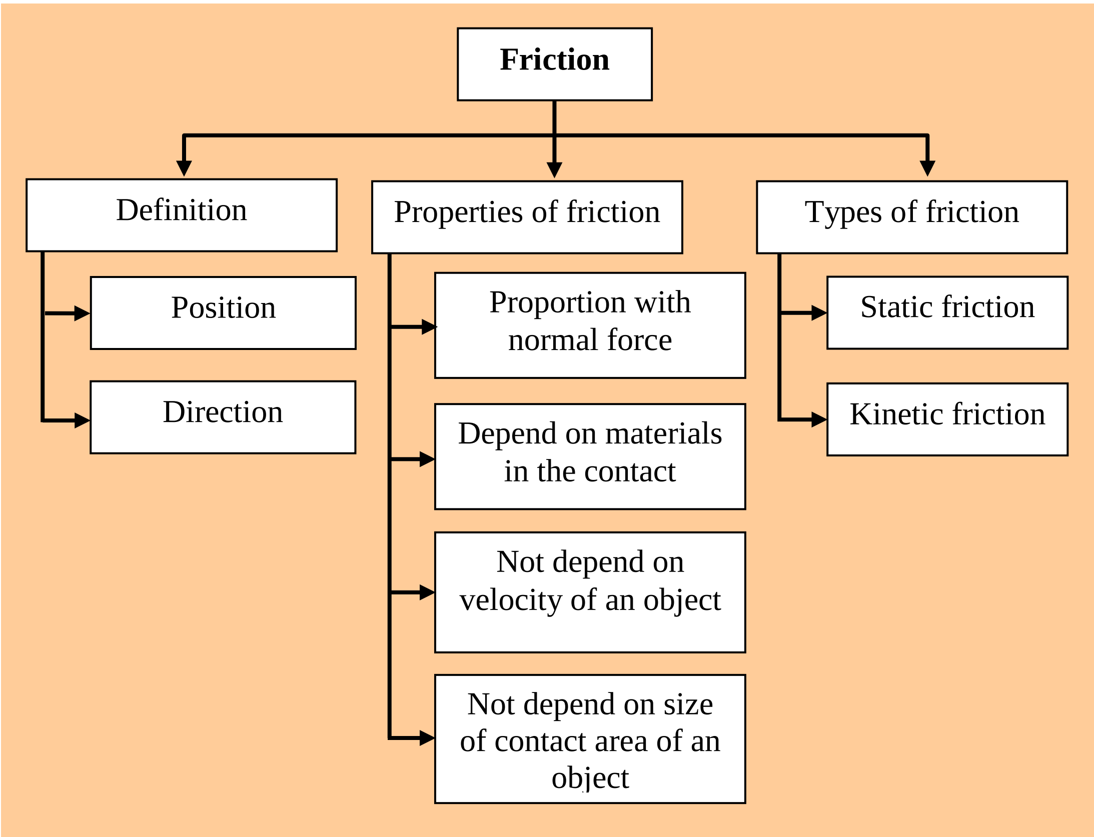


Figure 3.2: The frictional force core concepts for Thai high school students (IPST, 2008)

These assumptions ignore the cases of a very small area digging into another surface and the high velocity of motion influenced by the air friction. Therefore, the frictional force is proportional to the normal force (at the same friction's coefficient) and the surface roughness. It is independent of the area of contact and the velocity of motion.

3.2 Step II: Creating the Open-Ended Questions as the FFCS

To check the students' understanding concerning the frictional force concepts, we constructed the conceptual open-ended questions of frictional forces called **"Frictional Force Conceptual Survey: FFCS"** based on the core concepts as shown in Figure 3.2. Moreover, the preliminary results and the outcomes of reviewing the literature focusing on the alternative concepts were also applied in this development. Questions of FFCS are based on everyday life contexts, for example, holding the glass, pushing the clothespress, kicking the ball, riding the bicycle and pushing the cart. The questions ask students to answer and give reasons for each situation. We constructed the first version of FFCS with 25 items, and required about 40 minutes to complete the survey. The first version of FFCS was tried with a number of students and evaluated by physics experts and the statistical methods. The details will be clearly illustrated in the next part. We then modified the FFCS again and again to reach the statistically acceptable version. Ultimately, the current version of the FFCS is composed of 20 items, 7 pages and required about 30 minutes to complete (as shown in Appendix B). The items of FFCS can be categorized into concepts as shown in Table 3.1.

Table 3.1: The corresponding concept for each item of FFCS

items	Concepts
1-13	definition of frictional forces (position and direction)
1-13	types of frictional forces (static and kinetic frictions)
14, 18	magnitude of the frictional force (independent of the apparent contact area of the objects)
15, 16, 17	magnitude of the frictional force (independent of the sliding speed of the objects)
19, 20	magnitude of the frictional force (dependent on the texture of the object)

3.3 Step III: Modifying and Evaluating the Efficiency of the FFCS

The FFCS was evaluated and modified to be the statistically satisfactory survey. The statistic techniques used to assess the FFCS in this research are (1) the content validity test by using the Item-Objective Congruence Index (the IOC index), (2) the item difficulty index, (3) the item discrimination index and (4) the reliability test by using the Kuder-Richardson formula 21 method (KR-21). Results are discussed as follows.

3.3.1 Content Validity Test (IOC index)

The FFCS was evaluated the content validity by using the Index of the Item-Objective Congruence (IOC index) (Rovinelli & Hambleton, 1977). The IOC index can be computed by using the following equation;

$$IOC_k = \frac{\Sigma R}{N}$$

where IOC_k is the index of the Item-Objective Congruence of item *k*,

ΣR is the total score of item *k* from the content experts, and

N is the number of content experts.

In this study, we invited five experts (N=5), who are physics instructors in Thai universities with more than ten years experiences in teaching and doing research, to measure the content validity of FFCS via the IOC index. We constructed a table for each expert to use during the item validation. An example of the IOC index table is shown in the Appendix A. Each expert assessed the agreement of each item with the stated purpose for the item, and marked: agree (+1 point), in which the item and its purpose correlated, not sure (0 point), or disagree (-1 point), in which the item and its purpose did not correlate. We averaged the scores from all experts for one item.

For the interpretation, based on the suggestions of the research of Rovinelli and Hambleton in 1977, that was if there were five context experts, who measured the IOC index of the test, the test was acceptable if at least four of five experts marked agree (+1 point) and the other marked not sure (0 point) with the item and its purpose. Obviously, it has required at least 80% agreement of the content experts for an acceptable item. Therefore, our items with Index of Item-Objective Congruence $\geq$ 0.80, equivalent to overall agreement that the item matched its stated objective, were selected for inclusion on the FFCS. We also modified some items based upon expert suggestions.

Moreover, these items were administered to 23 undergraduates (N=23) who have studied frictional forces in the university level. To check students' interpretations of items in which whether it matches the researcher intentions or not, we analyzed these students' responses without the considering of scientific or alternative conceptions. We found that all participated undergraduates answered the item that matched researcher intentions. Clearly, it is 100% of matching between researcher and student interpretations of each item of FFCS.

3.3.2 Item Difficulty Index (P index)

Item difficulty index (P index) aims to measure the difficulty of each item of the test. It is represented by the ratio of the number of test takers who correctly answered the items to the total number of test takers, as shown in the following equation;

$$P = \frac{N_{correct}}{N_{total}}$$

where P is the item difficulty index,

$N_{correct}$ is the number of test takers who correctly answered the item, and

N_{total} is the total number of test takers.

From the calculation, the range of P index is between 0 and 1. Zero is represented that no one correctly answered the item of the test that means the item is too difficult. One is represented that everyone correctly answered the item of the test that means the item is too easy. However, the P index is accepted for one item obtained between 0.3 and 0.8, which means of about 30%-70% of test takers can correctly answer the item (Hernandez, 2009).

In this research, we started from calculation the P index of each item of the first version FFCS and the items with lower than 0.3 or higher than 0.8 of P indices were discarded. The FFCS was modified to achieve the desired range of P indices (0.3-0.8) from year 2008 to 2010. Results of the item difficulty index testing were clearly reported in Table 3.2 by which we calculated the average P index as the representative of the whole data.

Moreover, Figure 3.3 shows the P index of each item of the current version of FFCS (20 items) administered by 160 students (N=160) in year 2010. We found that item 5 was quite difficult for these students (P index = 0.32). For item 5, we asked students to identify the position and direction of frictional force in the case of holding up the glass without sliding. This situation concerns the frictional force in the vertical direction, and the magnitude of frictional force is not equal to the product of the friction coefficient and the normal force, which students are familiar, but is the weight of the glass. The other two items; item 17 and 18; are a bit difficult, as well. The P index of items 17 is 0.38. The concept of item 17 involves the magnitude of frictional forces that is independent of the speed of a sliding object. The same concept was also found in the item 16 illustrating 0.46 of P index. The P index of item 18 is 0.36. Item 18 is about the magnitude of frictional forces that is independent of the area of the contact objects. In contrast, items 1, 2 and 3 seem to be easy for these students. The P indices are almost 0.8. These relate to the position and types of frictional forces in horizontal plane. Overall, the average P index of current version FFCS is 0.52.

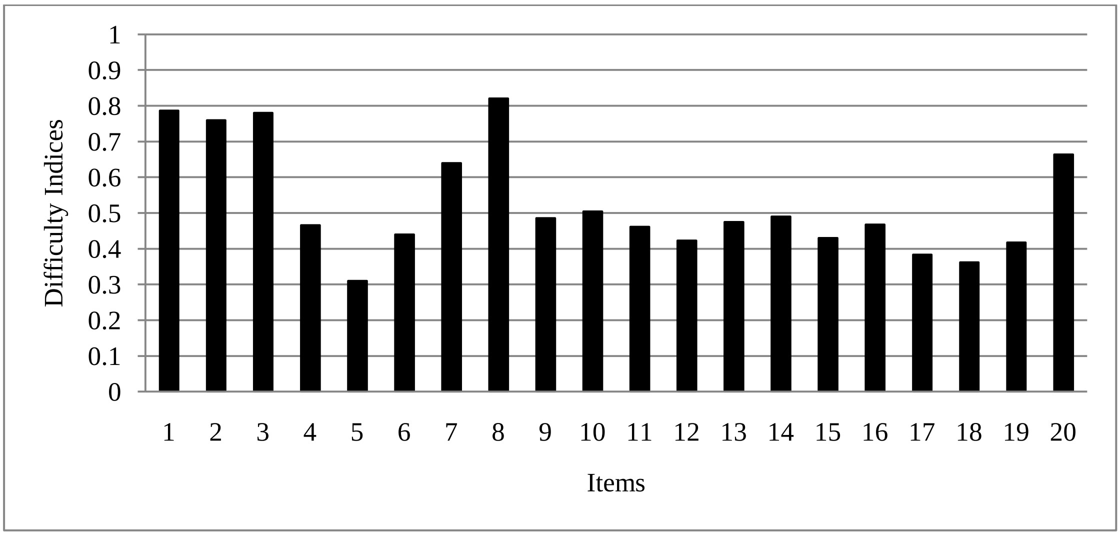


Figure 3.3: The item difficulty indices (P indices) of each item of FFCS administered by 160 students (N=160) in year 2010

3.3.3 Item Discrimination Index (D index)

Item discrimination index (D index) aims to measure how well the item discriminate the test takers into high-performing and low-performing students. This is based on the expectancy that the high-performing students would select the correct answer for each item more often than the low-performing students. The D index can be computed by using the following equation;

$$D = \frac{N_H - N_L}{N/4}$$

where N_H is the number of correct test takers in high-performing group,

N_L is the number of correct test takers in low-performing group, and

N is the total number of test takers.

To calculate the item discrimination index (D index) of the FFCS, we started from ranking the total scores of the FFCS takers in from minimum to maximum scores. The first 25% of the number of FFCS takers who took low scores was defined as the low-performing group. The first 25% of the number of FFCS takers who took high scores was defined as the high-performing group (Abdullah, 2006). The range of D index is between -1 and 1. Minus one is the worst that means the item cannot discriminate the test takers into high-performing and low-performing groups. In contrast, one is the best that means the item can completely discriminate the test takers into high-performing and low-performing groups. In general, the item yielding positive discrimination index of 0.30 and above are quite good discriminators (Zurawski, 1998).

The FFCS items, which D index is lower than 0.3, were modified from year 2008 to 2010 to achieve the desired indices (≥ 0.3). Results of the item discrimination index testing were clearly shown in Table 3.2 by which we calculated the average D index as the representative of the whole data.

Moreover, Figure 3.4 displays the D index of each item of the current version of FFCS administered to 160 students (N=160) in year 2010. We found that items 1, 2 and 3 are the lowest discriminators. Almost 80% of students can correctly answer these items. These students are from both high-performing and low-performing groups with almost equal amount. Indeed, these three items have not enough efficiency to discriminate the students into high-performing and low-performing groups. For item 8, it is also low discriminator (low D index), but its difficulty index (P index) is in the middle level. There are lower students correctly answering this question than that of items 1, 2 and 3. Similarly, it is possible that students, who can correctly answer this item, are from high-performing and low-performing groups with almost equal amount. In contrast, there are more students in the high-performing group, who can correctly answer of items 4, 5 and 9, than that of low-performing group. Therefore, these three items show the highest D indices. Although, there is only 32% of students can correctly answer item 5 (P index = 0.32), most are from the high-performing group and a few are from the low-performing group. The average D index of the FFCS is 0.51.

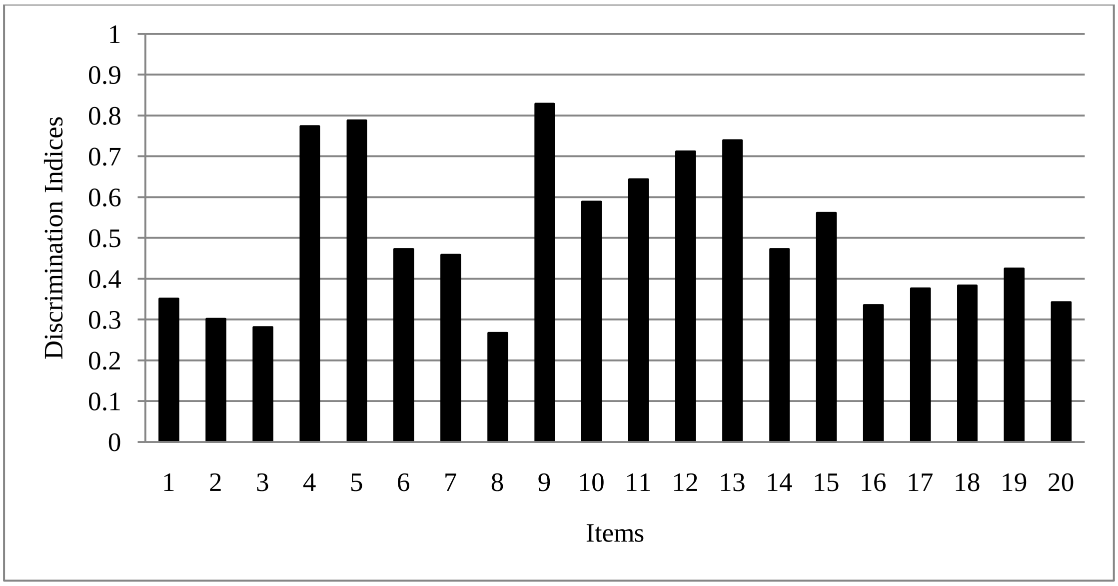


Figure 3.4: The item discrimination indices (D indices) of each item of FFCS administered by 160 students (N=160) in year 2010

3.3.4 Reliability Test (KR-21)

The FFCS was measured the internal consistency of reliability by using the Kuder-Richardson formula 21(KR-21) method, which based on the variance of the test. The KR-21 shows how consistent participants' responses are among the items on the test. It calculates an index based on the number of items, the proportion of the responses to an item that are correct, the proportion that are incorrect, and the variance of both. The KR-21 can be computed by the following equation;

$$KR\text{-}21 = \left(\frac{k}{k-1}\right)\left(1 - \frac{\bar{x}(k-\bar{x})}{ks^2}\right)$$

where k is number of items on the test,

$\bar{x}$ is the mean score of the test, and

s^2 is the variance of the test (Variance is the standard deviation squared.).

The KR-21 index lies in the range of 0-1. The higher values indicate that there is a strong relationship between items on the test. In common, the test is reliable if it takes KR-21 greater than 0.7 (Grier, 1975). Results of KR-21 testing of the FFCS from year 2008 to 2010 are shown in Table 3.2

Table 3.2: Results of the statistical test; the item difficulty index (P index), item discrimination index (D index) and the KR-21 reliability index of the FFCS from year 2008 to 2010.

Statistical Test		Item difficulty index (P index)	Item discrimination index (D index)	KR-21 reliability index
Possible values		[0, 1]	[-1, 1]	[0, 1]
Desired values		0.3-0.8	≥ 0.3	≥ 0.7
Year	**Number of samples**			
2010	160	0.53**	0.51**	0.69**
2009	63	0.39**	0.41**	0.65**
2008	177	0.22*	0.44*	0.66*
	241	0.31*	0.33*	0.19*

*average of 25 questions

**average of 20 questions

3.4 Summary

This chapter presented how to develop the "Frictional Force Conceptual Survey: FFCS", in order to utilize for extracting the alternative concepts and for assessing the learning module. The FFCS was constructed based on the key concepts of frictional forces mentioned in the Basic Education Core Curriculum B.E. 2551 (A.D. 2008) of Thailand, the preliminary results and the previous literature. Moreover, the FFCS was evaluated in term of the content validity (IOC index), the item difficulty index (P index), the item discrimination index (D index) and the KR-21 reliability index. It was modified from year 2008 to 2010 to reach the statistically acceptable version. Ultimately, there are 20 open-ended items of FFCS. The FFCS was used to survey the alterative concepts of Thai high school students. These alternative concepts acted as the primary resources for designing the learning module addressed will be discussed in the next chapter.

CHAPTER IV
FRICTIONAL FORCE LEARNING MODULE

This chapter presents the obtaining of the frictional force learning module. It starts from considering the core concepts of the frictional force provided for Thai high school students. Since the learning module constructed by the researchers is based on the alternative concepts of Thai students; the students' prior knowledge is investigated in the next step. Then we create the frictional force learning module by using the Interactive Lecture Demonstrations (ILDs) and the hands-on approaches. Our learning module consists of 3 major demonstration sets, worksheets, lesson plans and the Frictional Force Conceptual Survey (FFCS). Each component of the module will be clearly addressed in this chapter.

Since our frictional force learning module has been developed for Thai high school students; what Thai students have to learn regarding the frictional force concept based on the curriculum is the first necessary. As mentioned in the previous chapter, the Basic Education Core Curriculum B. E. 2551(A. D. 2008) of Thailand reported by IPST in 2008 identified that key concepts of the frictional forces for Thai high school students are the directions, types and properties.

To design the efficient frictional force learning module, which covers the key concepts of frictional forces, we used the alternative concepts as the primary resources. We have investigated the alternative concepts of Thai high school students by using the frictional force conceptual survey (FFCS).

4.1 Investigate Students' Alternative Concepts of Frictional Forces

In general, 5^{th}, 9^{th} and 10^{th} Thai graders are required to learn the frictional force concepts. To survey the alternative concepts held by students, who have already learned the frictional force, we employed the FFCS with 241 entry-level university students in the science major (70% female). The average age of the samples was 18 years. The FFCS, used in this process, is the first version, which was evaluated the content validity (IOC index) by physics experts and the matching interpretation by a group of students. The 241 participants needed of about 40 minutes for completing 20 items of the FFCS. The researchers then read and grouped the students' responses in each item. For the item that students wrote the unclear answers, we have invited some of them (N=40) to individual interview. This process took of about 10-15 minutes per students. Results of the FFCS administered by these 241 students, coupled with the interview results, are reported in this part by concepts namely; (1) directions of frictional forces, (2) types of frictional forces, (3) effect factors to the frictional force magnitude.

4.1.1 Students' Alternative Concepts on Directions of Frictional Forces

We used 13 items of FFCS (item 1-13 of the FFCS in Appendix B) to detect students' alternative concepts on directions of frictional forces. The items concern situations in everyday lives. For instance, we asked students to identify the direction of the frictional force acted by the thumb acts on the glass surface while being lifted up (item 5), the ground on the soccer player's foot while he is running (item 6), and the inclined surface on the wheel while the wheel is moving down (item 8).

Item 9 is an example of the items we used to survey students' alternative concepts on directions of a frictional force. The situation involves a man, who is pushing a cart from right to left hand side (Figure 4.1). Then we asked students to draw the frictional force direction that the ground acts on the cart wheel.

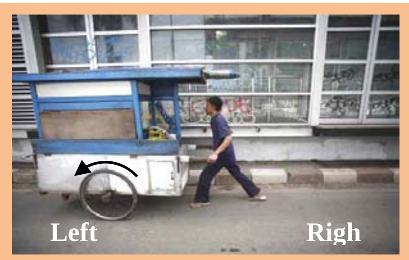


Figure 4.1: A man is pushing a cart from right to left hand side. In what direction does the frictional force from that the ground acts on the cart wheel? (Item 9 of FFCS)

For this item, the correct answer is that the direction of the frictional force that the ground acts on the cart wheels point to the right hand side. We found that 80% of students selected the correct answer, but they gave the reason that since the cart move to the left, the frictional force must point to the right. They said because the frictional force direction is always opposite with the object movement. This is an incorrect concept. Clearly, although these students got score from this item, they still held the alternative concept. As well, the students used this incorrect concept to solve other items of FFCS comfirmed by their explanation. Moreover, some students believed that the frictional force direction is always opposite to that of the force exerted on the object. Some believed the direction of the frictional force is opposite to that of acceleration, as found in other items used to extract student understanding on directions of frictional forces.

4.1.2 Students' Alternative Concepts on Types of Frictional Forces

Items 1-13 of FFCS also involve with the types of frictional force. We asked students to specify the static friction, kinetic friction or no friction between the contact areas of each situation.

Item 5 is an example (Figure 4.2). We asked that while we are lifting up a glass with a constant velocity and no sliding, does the frictional force exist between the glass surface and the thumb. If yes, which type of the frictional force between the surfaces should be?

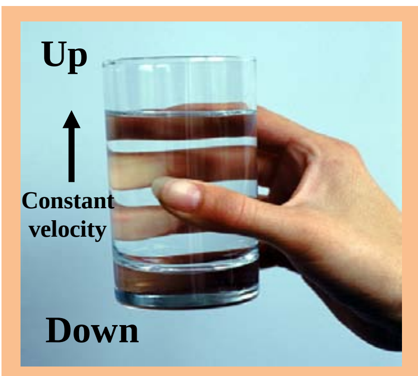


Figure 4.2: We are lifting up a glass with a constant velocity and no sliding, does the frictional force exist between the glass surface and the thumb. If yes, which type of the frictional force between the surfaces should be? (Item 5 of FFCS)

The correct answer of this item is that the static friction exists between the glass surface and the thumb because of no relative motion between them (no sliding). We found that 75% of these students said that the kinetic friction existed between the glass surface and the thumb. They believed that the glass moves, so the kinetic friction always acts between the contact areas. This is an alternative concept. Moreover, we found that some students believed that if an object moves with a constant velocity, the net force is zero; so there is no frictional force.

4.1.3 Students' Alternative Concepts on Effect Factors to the Frictional Force Magnitude

We used a group of FFCS items to investigate the alternative concepts on effect factors to the magnitude of frictional forces. Examples are found in the items 14-20. An example is about a motorist, who has an accident (item 14). The situation is that the motorist slides on his back along the road surface (Figure 4.3). The frictional force between his back and the ground exists. The question is that does the magnitude of the frictional force during the sliding on his back differ from that on his side along the road surface, and why.

Figure 4.3: A motorist got an accident and slid on his back along the road surface. The frictional force between his back and the ground exists. Does the magnitude of the frictional force during the sliding on his back differ from that on his side along the road surface, and why? (Item 14 of FFCS)

The correct answer of this item is that the magnitude of the frictional force during the sliding on his back does not differ from that on his side because of the same surface roughness. But we found that over 80% of students answered that the magnitude of the frictional force during the sliding on the motorist's back differs from that on the motorist's side along the road surface. Fifty seven percent of students in this group said that sliding on his back generates greater magnitude of frictional force. They gave the reason that the larger contact areas generate the greater frictional force magnitude. Some gave the reason that since his weight pressed on the back is more than that on the side, the magnitude of the friction force from sliding on his back is greater. Twenty seven percents of students in this group said that sliding on his back generates less magnitude of frictional force. They gave the reason that since his weight pressed on the back is less than that on the side, the magnitude of friction forces from sliding on his back is smaller. Clearly, most students held the alternative concepts that the frictional force magnitude depends on the size of contact areas.

Another example, we used to investigate the alternative concept on effect factors to the frictional force magnitude, is about an elephant pulling a log (item 15). In this situation, we asked students to compare the frictional force magnitude between (1) the elephant is walking to pull the log and (2) the elephant is running to pull the log with the same ground and force (Figure 4.4).

Figure 4.4: An elephant is pulling a log. Compare the frictional force magnitude between (1) the elephant is walking to pull the log and (2) the elephant is running to pull the log with the same ground and force. (Item 15 of FFCS)

The correct answer of this item is that the frictional force magnitudes for both events are the same because of the same surface roughness. Results illustrated that 87% of these students answered that the frictional force magnitudes, which the ground acts on the log for both events, are not equal. They said that there exists a larger magnitude of frictional forces for a faster moving elephant (running). This is an incorrect idea. For short, most students held the alternative concepts that the frictional force magnitude depends on the speed of the moving object. These two alternative concepts on effect factors to the frictional force magnitude are also revealed by other FFCS items in different contexts.

Finally, we summarized students' alternative concepts of frictional forces found in this research in Table 4.1. These are categorized by concepts namely (1) directions of frictional forces, (2) types of frictional forces, and (3) effect factors to the frictional force magnitude. Some of them have been published (Prasitpong & Chitaree, 2010).

Table 4.1: The summary of Thai students' alternative concepts of frictional forces found in this research

Frictional Force Topics	Students' Alternative Concepts
1. Directions of frictional forces	• The direction of frictional forces is always opposite to the motion of the object. • The direction of frictional forces is always opposite to that of the force exerted on the object. • The direction of frictional forces is opposite to that of acceleration.
2. Types of frictional forces	• When the object moves, the kinetic friction always acts between the contact areas. • When the object moves with a constant velocity, the net force is zero, so there is no frictional force as well.
3. Effect factors on the frictional force magnitude	• The magnitudes of frictional forces depend on the apparent contact areas. • The magnitudes of frictional forces depend on the sliding speed of the object.

Since, students learn and construct the new ideas from the prior knowledge following the constructivist learning theory; the alternative concepts found in this process are used as key resources for designing the frictional force learning module in the next step.

4.2 Invention of the Frictional Force Learning Module

To help Thai high school students learn frictional force concepts we construct the learning module based on the students' prior knowledge, coupled with the hands-on and ILDs approaches. Our frictional force learning module consists of 4 main components (Figure 4.5). These are;

(1) three demonstration sets; set A for frictional force direction demonstration, set B for static and kinetic friction demonstration, and set C for demonstration of the effect factors on the magnitude of the frictional force,

(2) worksheets,

(3) four lesson plans, and

(4) frictional force conceptual survey (FFCS) as the evaluation tools of this learning module shown in Chapter 3.

Details of each component will be explained in the following section.

4.2.1 Three Demonstration Sets

We aim to design the demonstration sets to encourage and help students visualize in the characteristics such as directions, types and magnitudes of frictional forces. This provides an opportunity to students to have prediction and discussion about the scientific concept in the classroom (Julien, 2006). In this research, we designed three main demonstration sets based on Thai students' misunderstanding on frictional forces. These concern (1) directions of frictional forces called "set A", (2) types of frictional forces called "set B" and (3) effect factors to the magnitude of frictional forces called "set C". These demonstration sets were tried and modified following both student and expert suggestions. Some of them were published (Prasitpong et al., 2010).

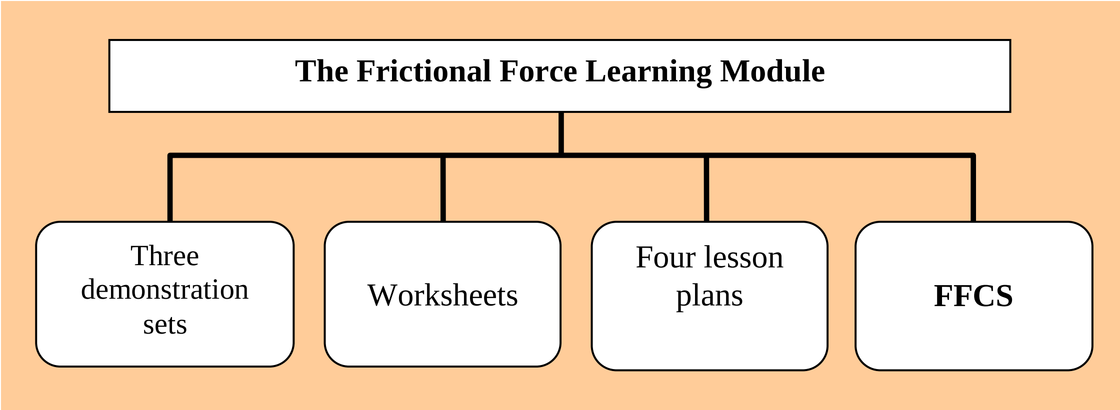
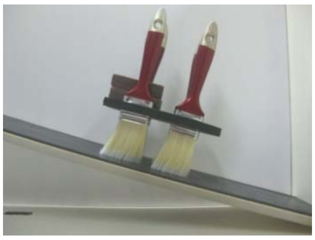
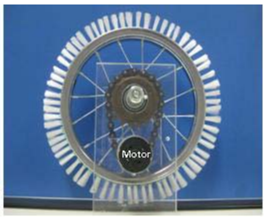


Figure 4.5: Four components of the frictional force learning module designed by the researchers

4.2.1.1 Demonstration set A: frictional force directions

Set A is the demonstration, which is used to teach the concepts of frictional force directions. Demonstration set A consists of 4 sub-sets of devices. These involve the demonstration of frictional force directions in 4 situations namely; set A1 for horizontal plane, set A2 for vertical plane, set A3 for inclined plane, and set A4 for the object rotation. Devices are made of brushes such as toothbrush, paintbrush, and clothes brush as shown in Table 4.2. We demonstrate directions of frictional forces via the bristles' tips. Learners will observe the bristles' tips in each situation, discuss with their peers and instructor by using the free-body diagram, and construct their own concept that the bristles' tips point to the direction of frictional forces originated by the ground acting on the object.

Table 4.2: Devices and how to use the set A for frictional force direction demonstration; horizontal plane (A1), vertical plane (A2), inclined plane (A3), and the object rotation (A4)

Demonstration sets	Devices/ How to use
A1: horizontal plane 	***Device:*** a toothbrush ***How to use:*** Gently push a toothbrush horizontally placed on a hand and observe the direction of bristles' tips.
A2: vertical plane 	***Devices:*** 1) a paintbrush, 2) a chopstick, 3) a stand, 4) a rubber plate (10x15 cm^2) ***How to use:*** Suspend a paintbrush by using a chopstick clamped by a stand. The chopstick allows the paintbrush to rotate around the horizontal axis. Then lightly touch the paintbrush with the rubber plate standing upright and observe the direction of bristles' tips.
A3: inclined plane 	***Devices:*** 1) four paintbrushes, 2) a rubber plate (10x15 cm^2) , 3) a wooden plate (15x50 cm^2) ***How to use:*** Place the four paintbrushes on a rubber plate placed on a wooden plate. Gently uplift both plates and observe the direction of bristles' tips.
A4: object rotation   **a non-driven wheel** (a wheel is rotated by pushing the acrylics handle) **a driven wheel** (a wheel is rotated by a motor)	***Devices:*** 1) two bicycle wheels (20 cm of diameter), 2) four acrylics plate (10x15 cm^2) , 3) 140 bristle pieces, 4) two gears, 5) a motor (12 volt), 6) a chain, 7) a rubber belt, 8) a battery (12 volt DC) ***How to use:*** Glue bristle pieces around rim of two bicycle wheels. Place both wheels on the rubber belts held by acrylic plates. Rotate the wheels and observe the direction of bristles' tips.

Applications of demonstration set A for instructions

Set A1: Horizontal plane

Activities:

(1) A teacher uses a toothbrush to engage students in a class.

(2) The teacher holds the toothbrush's handle. The bristles are arranged to freely rest vertically on the table. Then asks a question "*Does the frictional force exist between the table's surface and the bristle' tips? If yes, In what direction does the frictional force from the table act on the bristle' tips?*

(3) Students predict the answer, discuss with their peers and note the final prediction into the worksheet.

(4) The teacher gives toothbrushes to students to investigate the answers by themselves.

(5) The teacher asks more questions for the occurrence of the frictional forces and their directions; such as *when the toothbrush is gently pulled but still stop on the ground, and when the toothbrush is gently pulled with a constant velocity*.

(6) Students do experiments (Figure 4.6). Students and the teacher discuss the free-body diagram and conclude that the bristles' tips point to the direction of friction forces.

Figure 4.6: A student is trying an experiment by gently pulling the toothbrush's handle, with its bristles vertically placing on her hand.

Set A2: Vertical plane

Activities:

(1) The teacher asks a question; *if a mobile phone is touched and rested on the rubber plate standing upright (shown in Figure 4.7A), does the frictional force exist between the rubber's surface and the mobile? If yes, in what direction does the frictional force from the rubber acting on the mobile?*

(2) By using the same concept with the former experiments, students predict and discuss with their peers.

(3) The teacher gives demonstration set A2 to students.

(4) Students do an experiment by replacing the mobile with the brush. The brush (mobile) cannot move downward by their weight due to the existence of the frictional force. The direction of the frictional force the frictional force for the situation of the top surface of the rubber plate acting on the bristles' tips can be represented by bristle' tips pointing to direction as shown in the Figure 4.7(B).

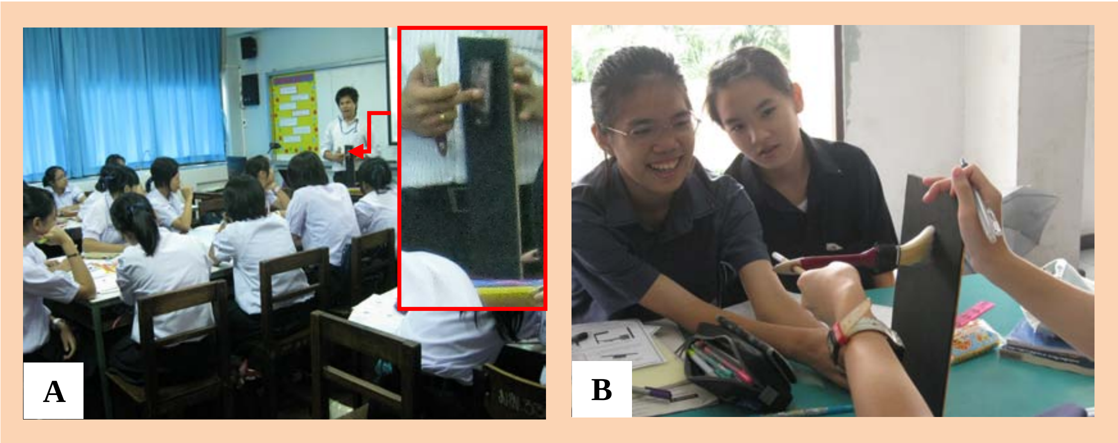


Figure 4.7: (A) a mobile phone is touched and rested on the rubber plate standing upright shown by the teacher, (B) students are doing an experiment as a group.

Set A3: Inclined plane

Activities:

(1) The teacher gives demonstration set A3 to students (Figure 4.8 A).

(2) The teacher asks questions; *when we place the paintbrushes on the rubber plate like Figure 4.8A; does the frictional force exist between the rubber's surface and the bristle' tips? If yes, in what direction does the direction of the frictional force from the rubber act on the bristle' tips?*

(3) Students predict, discuss with their peers, note their prediction into worksheet and do experiment.

(4) The teacher gives more questions for the occurrence of the frictional forces and their directions; such as *when the rubber plate is slowly uplifted but a set of the paintbrushes still rest on that plate (shown in Figure 4.8B).*

(5) Students do experiments as a group (Figure 4.8C and D).

Figure 4.8: (A) demonstration set A2, (B) the rubber plate is uplifted but a set of the paintbrushes still rest on that plate, (C) and (D) students are doing experiments as a group.

Set A4: Object rotation

Activities:

(1) A student is asked for voluntarily participate is riding to ride a bicycle in front of the class (Figure 4.9).

(2) The teacher asks a question; *what are the frictional force directions that the ground acts on the front and the rear wheels of the bicycle?*

(3) Students predict, discuss with their peers and note their prediction into worksheet.

(4) The teacher collects the students' prediction for the whole class and note on the blackboard.

(5) The teacher explains the structure of the bicycle that the rear wheel is rotated by pedaling but the front wheel is rotated by the frictional force.

Figure 4.9: A student is riding a bicycle in front of a class to engage his classmates to predict the frictional force directions that the ground acts on the front wheel and the rear wheel of the bicycle.

(6) The teacher shows the demonstration set A4. This consists of 2 wheels; (1) a non-driven wheel (Figure 4.10A) as the representation of the front wheel, and (2) driven wheel (Figure 4.10 B) as the representation of the rear wheel.

(7) A non-driven wheel is pushed by the acrylic handle at the center of mass. This makes the wheel to slide but not rotate. The non-driven wheel is rotated by the frictional force. The direction of frictional force is shown by the bristles' tips bending.

(8) The teacher turns on the motor to rotate the driven-wheel.

(9) Students observe the directions of the bristles' tips and conclude that the directions of frictional forces that the ground acts on the front and the rear wheels of the bicycle are opposite.

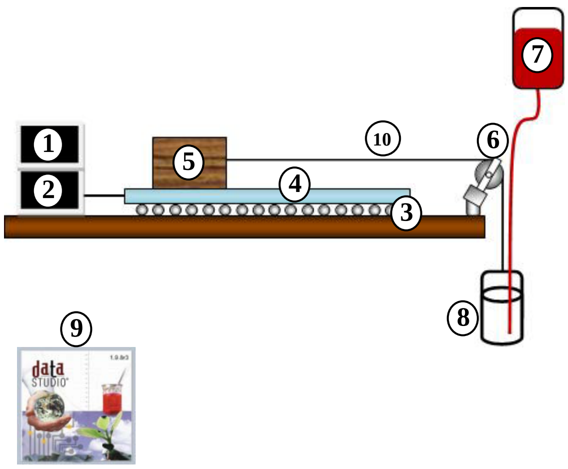
(10) The teacher discusses and summarizes the students' ideas before and after the demonstration (Figure 4.10 C and D).

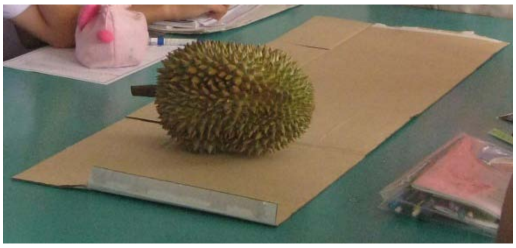
Figure 4.10: (A) a non-driven wheel, (B) a driven wheel, (C) and (D) students and the teacher discuss each other.

4.2.1.2 Demonstration set B: types of frictional forces

Set B is the demonstration, which is used to teach the concepts of types of frictional forces. Demonstration set B consists of 2 sub-sets of devices; B1 and B2 (Table 4.3). B1 shows the graphs between frictional forces and applied forces. An object is gently pulled by the constantly increasing forces (the applied forces) until the object moves. Force sensor records the magnitudes of the existing frictional forces between the object surface and the ground (y-axis) with times (x-axis), and plots the graphs. Learners observe the outstanding characteristics of the graphs, discuss with their peers and instructor, and construct their own concepts about static and kinetic frictions. B2 shows the trace of the durian movement in cases of (1) the rolling without skidding and (2) sliding. Students observe the trace of the movement on the paper crate and learn about the static and kinetic frictions.

Table 4.3: Devices and how to use the set B for types of frictional force demonstration; generating graphs of frictional forces and times (B1), and trace of the durian movement (B2)

Demonstration sets	Devices/ How to use
B1: Generating graphs of frictional forces and times 	***Devices:*** 1) Motion sensor, 2) Force sensor, 3) bearing balls placed on the plate, 4) an acrylic plate(20x150 cm^2), 5) a wooden block (10x15x5 cm^3), 6) a pulley, 7) a saline solution bag, 8) a bucket, 9) data studio program, 10) small rope. ***How to use:*** Set up the devices as shown in the left Figure and connect the data studio program to the computer. Drip the red water (in the saline solution bag) in the bucket to increase the forces, which pull the wooden block to move. Observe the graph of frictional forces existing between the wooden block surface and the acrylic plate (y-axis) with times (x-axis) shown on the computer screen.

B2: Trace of the durian movement 	***Devices:*** 1) a durian, 2) a paper crate ***How to use:*** Gently move a durian on the paper crate by (1) rolling without skidding and (2) sliding. Observe the trace on the paper crate.

Applications of demonstration set B for instructions

Set B1: Generating graphs of frictional forces and times

Activities:

(1) The teacher sets up the demonstration set B1 (shown in Figure 4.11) and explain the demonstration to students.

(2) Students predict the shape of the graph between the frictional forces existing between the wooden block surface and the acrylic plate (y-axis) and times (x-axis) when the red water is dripping into the bucket, discuss with their peers and note the final prediction into worksheet.

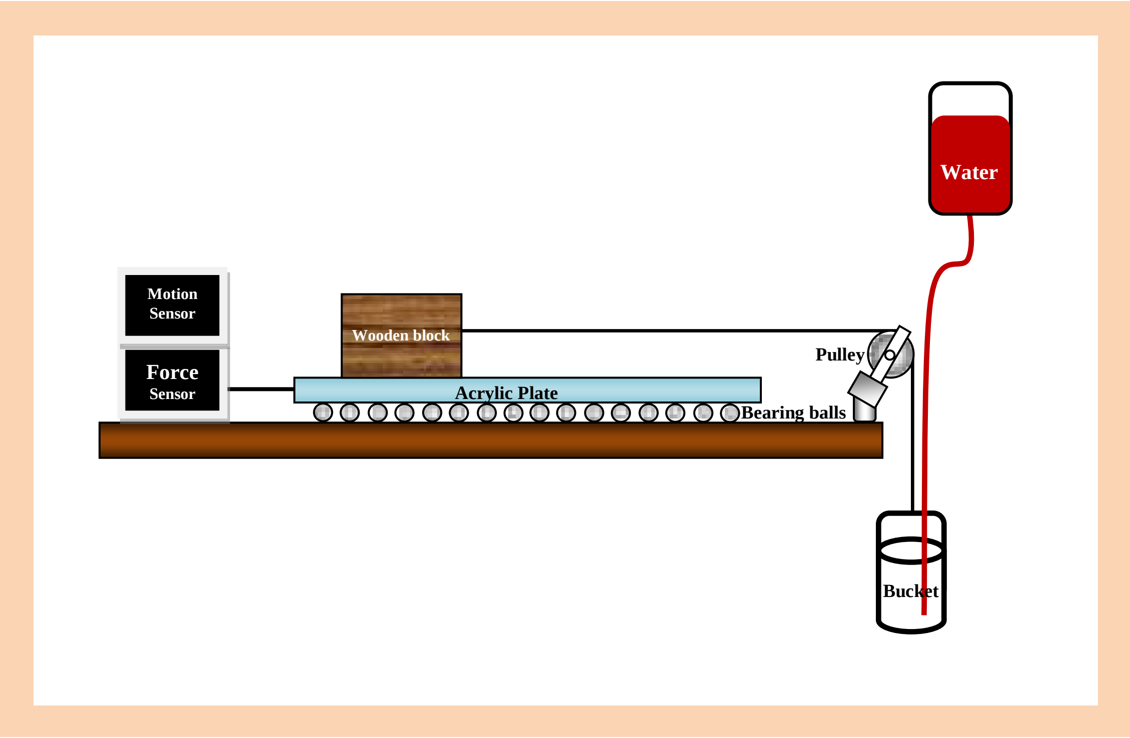


Figure 4.11: Components of the demonstration set B1 regarding types of frictional forces.

(3) While the demonstration is being performed, the force-time and position-time graphs are shown on the computer screen. Examples of graphs are shown in Figure 4.12.

(4) To display the wooden block motion, we also show the position-time graph Figure 4.12 B).

(5) While the red water is dripping into the bucket, the force for pulling the wooden block is constantly increasing. The frictional force existing between the wooden block surface and the acrylic plate occurs. There are both static and kinetic frictions illustrated by the graph.

(6) Students discuss each other about the static friction, the maximum static friction and the kinetic friction.

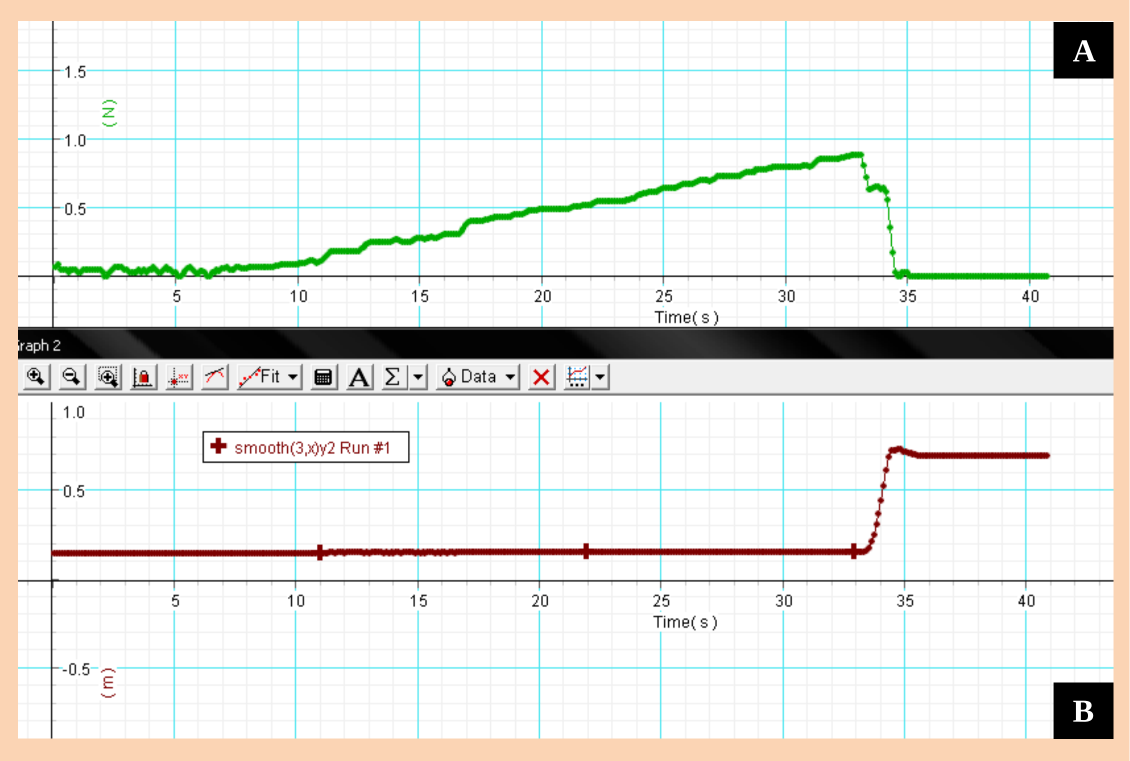


Figure 4.12: (A) a graph between the frictional forces existing between the wooden block surface and the acrylic plate (y-axis) and times (x-axis), (B) a graph between positions (y-axis) and times (x-axis) of the wooden block.

Set B2: Trace of the durian movement

Activities:

(1) The teacher uses durian to engage students in class.

(2) The teacher places durian on the crate paper and asks students to predict the tract on the paper when he (1) rolls the durian without skidding, and (2) slides the durian (Figure 4.13 A).

(3) Students discuss with their peers and take note.

(4) The teacher shows the experiments (Figure 4.13 B).

(5) Students and teachers discuss and conclude that the point trails on the paper occurring form the rolling without skidding refer to the static friction. The line trails on the paper occurring from the sliding refer to the kinetic friction.

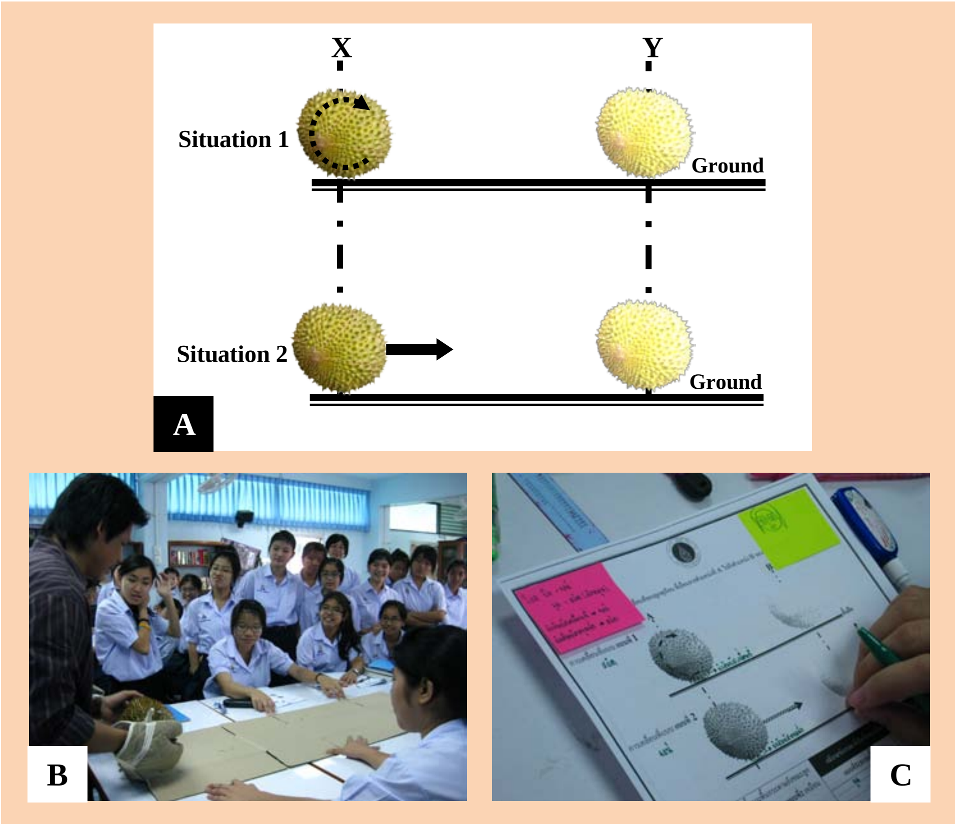
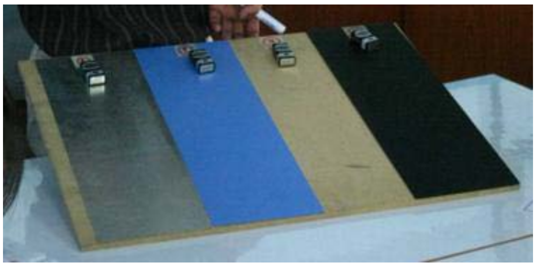


Figure 4.13: (A) A durian is moved by rolling without skidding and sliding, (B) the teacher shows the experiments, (C) students predict the experiments on the worksheet.

4.2.1.3 Demonstration set C: effect factors on the magnitude of frictional forces

Set C is the demonstration, which is used to teach the concepts of the effect factors on the magnitude of frictional forces. Demonstration set C consists of 2 sub-sets of devices; C1 and C2 (Table 4.4). C1 demonstrates that the magnitude of frictional forces depends on the material of the object. C2 demonstrates that the magnitude of frictional forces is independent of the size of contact area and the sliding speed of the object.

Table 4.4: Devices and how to use the set C for the demonstrations of effect factors on the magnitude of frictional forces; magnitude of frictional forces depends on the material of an object (C1), magnitude of frictional forces is independent of the size of contact area and the sliding speed of the object (C2).

Demonstration sets	Devices/How to use
C1: magnitude of frictional forces depends on the material of an object 	***Devices:*** 1) a Zinc plate(20x40 cm^2), 2) a Formica plate(20x40 cm^2), 3) a wooden plate(20x40 cm^2), 4) a rubber plate(20x40 cm^2), 5) a wooden plate (80x40 cm^2), 6) four alkaline batteries ***How to use:*** Stick Zinc plate, Formica plate, wooden plate and rubber plate on the big wooden board. Place the alkaline batteries on each plate and gently uplift the plate. Observe the movement of the batteries.
C2: magnitude of frictional forces is independent of the size of contact area and the sliding speed of the object	***Devices:*** 1) Motion sensor, 2) Force sensor, 3) bearing balls placed on the plate, 4) an acrylic plate (20x150 cm^2), 5) a wooden block (10x15x5 cm^3), 6) a motor (12 volt DC), 7) a step motor controller, 8) data studio program,9) small rope.

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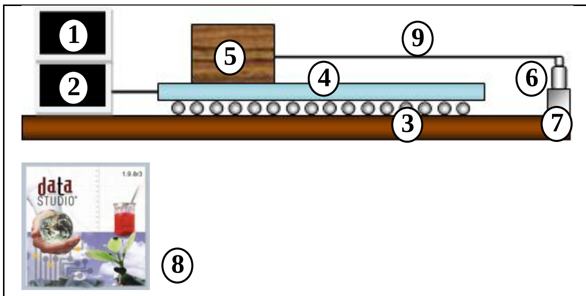
<td>
</td>
<td>How to use: Set up the devices as shown in the left Figure and connect the data studio program to the computer. Use motor pull the wooden block to move with different sides (different contact areas) but the same speed and observe the magnitude of frictional force recorded by the force sensor shown on the screen. Then use motor to pull the wooden block (same side or same contact areas) to move with different speed and observe the magnitude of frictional force recorded by the force sensor shown on the screen.</td>
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Applications of demonstration set C for instructions

Set C1: Magnitude of frictional forces depends on the material of an object

Activities:

(1) The teacher places 4 batteries (9V type and square shape) on the board covered by Zinc plate, Formica plate, wooden plate and rubber plate.

(2) The teacher gradually uplifts the board and asks students to predict which battery will arrive at the bottom of the inclined board first (Figure 4.14A).

(3) Students predict, discuss with their peers and take note.

(4) The teacher inclines the board of about 45 degrees with respect to the horizontal plane and releases the four batteries with the same time. Ask students to predict that which one will reach the bottom first (Figure 4.14B).

(5) Student and the teacher discuss and conclude that the magnitude of frictional forces depends on the surface roughness of the object.

Figure 4.14: (A) and (B) the teacher uplifts the board covered by Zinc plate, Formica plate, wooden plate and rubber plate and 4 batteries are placed on.

Set C2: Magnitude of frictional forces is independent of the size of contact area and the sliding speed of the object

Activities:

(1) The teacher explains the demonstration set C2. He uses the motor to pull the wooden block with the same speed but different side called J, K and L (Figure 4.15 A).

(2) Students are asked to predict the graph between the magnitude of frictional forces existing between the wooden block surface and the acrylic plate (y-axis) and times (x-axis) for each side (J, K and L) of the block. They discuss with their peers and note into the prediction worksheet.

(3) While the demonstration is being active, the graph of the magnitude of frictional forces and times is shown on the computer screen. To illustrate that the motor pulls each side of the block with the same speed, we also show the velocity-time graph of the movement of the wooden block (Figure 4.15B).

(4) With a given low speed of the object movement, the magnitudes of frictional forces existing between the object and the ground from different sizes of contact area are the same shown by the demonstration set. Clearly, Figure 4.15B shows that $\boldsymbol{F}_1 = \boldsymbol{F}_2 = \boldsymbol{F}_3$, where $\boldsymbol{F}_1$, $\boldsymbol{F}_2$ and $\boldsymbol{F}_3$ represent the magnitudes of frictional

forces existing between the wooden block sides J, K and L and the acrylic plate, respectively. So, student and the teacher discuss and conclude that the magnitude of frictional forces is independent of the size of contact area.

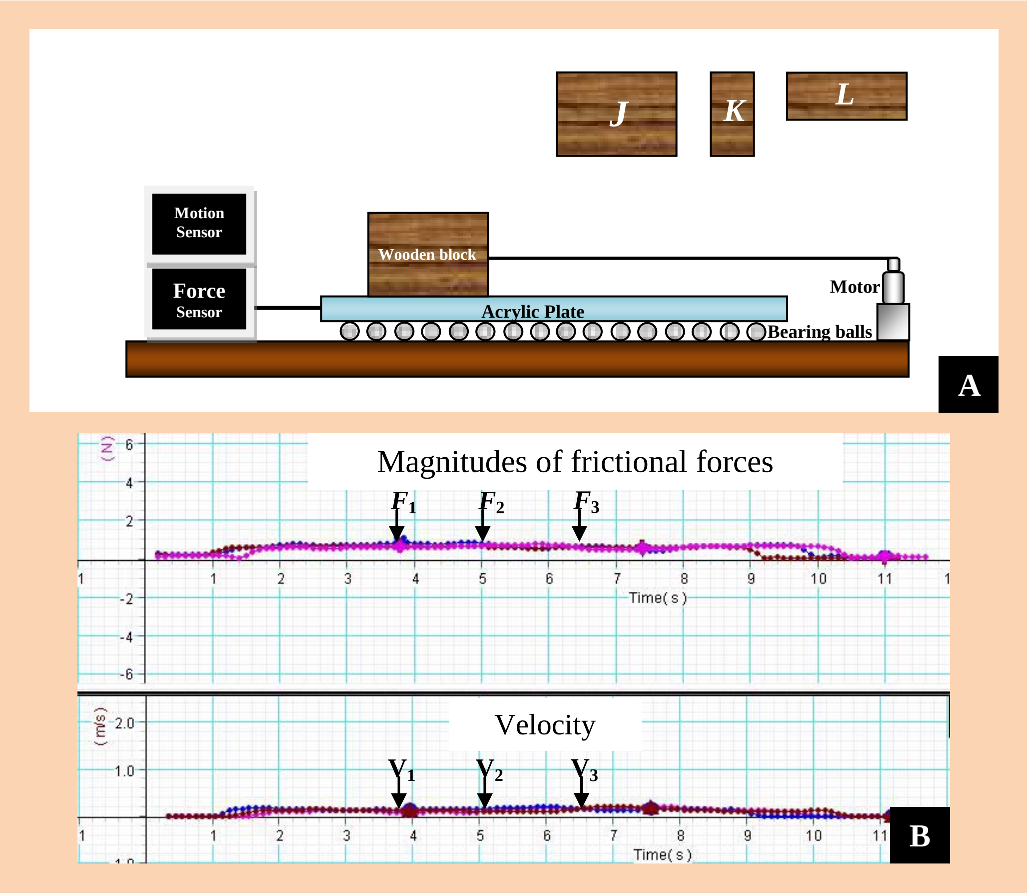


Figure 4.15: (A) demonstration set C2, (B) the graphs between the magnitude of frictional forces existing between the wooden block surface and the acrylic plate (y-axis) and times (x-axis) for each side (J, K and L) of the block (upper), and the velocity-time graph of the wooden block movement (lower).

(5) After that, students are asked to predict the graph between the magnitude of frictional forces existing between the wooden block surface and the acrylic plate (y-axis) and times (x-axis) for one side of the block but two different constant speeds ($\mathbf{V_2} > \mathbf{V_1}$). They discuss with their peers and note into the prediction worksheet.

(6) While the demonstration is being operated, the graph of the magnitude of frictional forces and times is shown on the computer screen. To illustrate that the motor pulls the wooden block with two different constant speeds, we also show

the velocity-time graph of the movement of the wooden blocks (the lower graph of Figure 4.16).

(7) The magnitudes of the frictional forces existing between the object and the ground, with two different constant speeds, are the same and this can be shown by the demonstration set. Clearly, Figure 4.16 shows that $\boldsymbol{F}_1 = \boldsymbol{F}_2$, where $\boldsymbol{F}_1$ and $\boldsymbol{F}_2$ are the magnitudes of frictional forces existing between the wooden block, moving with $\mathbf{V_1}$ and $\mathbf{V_2}$ ($\mathbf{V_2} > \mathbf{V_1}$), and the acrylic plate, respectively. So, student and the teacher discuss and conclude that the magnitude of frictional forces is independent of sliding speed of the object.

(8) Students further explore a different situation by using the motor to pull the block with a given acceleration and predict and discuss the magnitude of frictional force with time, and compare with the former demonstration.

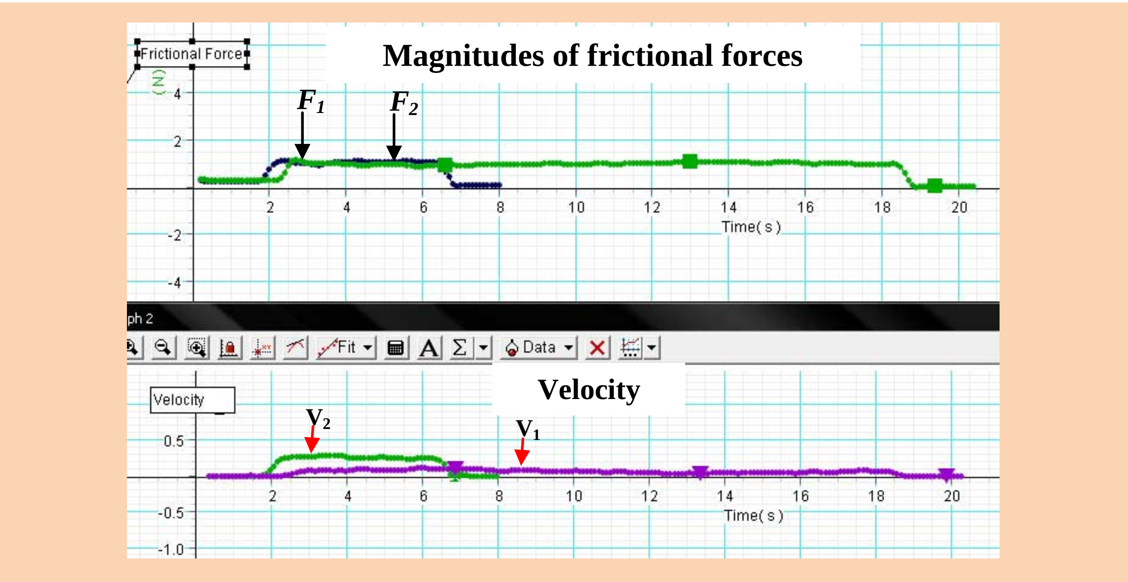


Figure 4.16: The graph of magnitude of frictional forces existing between the wooden block surface and the acrylic plate (y-axis) and times (x-axis) (upper), and the velocity-time graph of the block movement (lower).

In brief, we have constructed 3 main demonstration sets; set A, set B and set C for three main objectives of teaching frictional force concepts. Moreover, all demonstration sets are used with their worksheets. There are 3 part of a worksheet; prediction, result and conclusion parts. This will be explained in the following section.

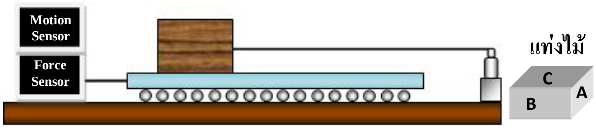
4.2.2 Worksheets

We have designed worksheets corresponding to the demonstration sets in the learning module. Each worksheet contains the main Figure of the experiment/demonstration and some introduction. A worksheet consists of 3 parts (1) prediction part, (2) result part, and (3) conclusion part for students to note their own understanding. In this frictional force learning module, we have totally developed 9 worksheets. Worksheets 1-4 are used in the demonstration set A concerning the frictional force directions. Worksheets 5-6 are used in the demonstration set B concerning types of frictional forces. Worksheets 7-9 are used in the demonstration set A concerning the effect factors on the magnitude of frictional forces as shown in Appendix D. In this section, we will show an example of worksheets (Figure 4.17). Worksheet 7 is used in the demonstration that the magnitude of frictional forces is independent of the size of contact areas of an object.

Both demonstration sets and worksheets, as mentioned, are utilized in classrooms following the lesson plans. We designed 4 lesson plans for the learning module based on the hands-on and Interactive Lecture Demonstrations (ILDs) approaches. These will be discussed in the next section.

ใบงานที่ 7

นำมอเตอร์ต่อเข้ากับชุดอุปกรณ์สาธิตแรงเสียดทาน ดังรูป แล้วดึงแท่งไม้ 3 ด้านคือด้านA ด้านB และด้านC ไปทางขวามือ ด้วยความเร็วคงที่ค่าหนึ่ง



1. เขียนกราฟแรงเสียดทานที่ผิวของอะคลีลิกกระทำต่อผิวด้านA ด้านB และด้านCของแท่งไม้

2. เปรียบเทียบกราฟแรงเสียดทานที่ผิวของแผ่นอะคลีลิกการทำต่อผิวของแท่งไม้ จากข้อ1

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3. สรุป

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Figure 4.17: Worksheet 7, an example of worksheets used in this learning module.

4.2.3 Lesson Plans

The lesson plans are created by the researchers to guide the learning operating. These lesson plans are based on the hands-on and Interactive Lecture Demonstrations approaches. It comprises 4 lesson plans covering 200 minutes of instruction (50 minutes for one lesson plan) corresponding to the standard curriculum for Thai high school students (IPST, 2008) on the concept of frictional forces. Objectives of each lesson plan are shown as follows;

Lesson plan 1**:** Free-body diagram and directions of frictional forces

Objectives: students are able to explain the free-body diagram and write arrows to indicate the directions of frictional forces in various different situations.

Lesson plan 2: Directions of frictional forces (Cont.)

Objectives: students are able to identify the positions and directions of frictional forces in various different situations.

Lesson plan 3: Types of frictional forces

Objectives: students are able to explain definitions of static friction, the maximum static friction and kinetic friction, and distinguish the types of frictional forces in various different situations.

Lesson plan 4: Effect factors on the magnitude of frictional forces

Objectives: students are able to explain that magnitude of frictional forces depends on the surface roughness, but not depends on the size of contact areas and the sliding speed of the object.

In this section, we introduce the lesson plan 3 as an example while the others are shown in the Appendix C.

Lesson Plan 3: Type of Frictional Forces

Time: 50 minutes

Objectives: students are able to explain definitions of static friction, the maximum static friction and kinetic friction, and distinguish the types of frictional forces in various different situations.

Teaching Tools:

(1) demonstration set B (B1 and B2)

(2) worksheet 5 and 6

(4) an LCD projector

(5) a computer

(6) lecture power point

Learning Process:

Time (minutes)	Learning steps	Learning Activities
5	Class engagement	Students watch the VDO clip about various situations of frictional forces and are asked to predict the types of friction forces.
30	1st step of ILD	A teacher describes the demonstration set B1 and gives students worksheet 5.
	2nd step of ILD	The teacher encourages students to predict the graph line between the times (x-axis) (This is used as the representation of the applied force) and the magnitudes of frictional forces (y-axis), measured by the force sensor, in the situation that the red water is slowly filled in the bucket until the weight of the bucket pulls the wooden block to move on the acrylic plate.
	3rd step of ILD	Students discuss their predictions with their peers in a small group. The teacher invites some students to explain their predictions to the class.

	4th step of ILD	Students note the final predictions on the prediction part of the worksheet 5.
	5th step of ILD	The teacher extracts the common student ideas and shows to the whole class.
	6th step of ILD	The demonstration set B1 is shown to the class. The red water is slowly added to the bucket. In the real-time, the screen displays the graph of times (x-axis) and frictional forces (y-axis).
	7th step of ILD	Teacher allows some students to explain the results, discuss each other and fill out in the result part of worksheet 5. In this demonstration, students are able to identify the types of frictional forces while the wooden block is slowly pulled by the bucket, but still rest at the same position shown by the position-time graph. The frictional force magnitude is slowly increased. This explains the characteristics of static friction. Suddenly, the more water is poured into the bucket, the faster the wooden block moves. Students observe that frictional force magnitude is quickly decreased and then constant with a given value. This presents the maximum static friction and the characteristics of kinetic friction.
	8th step of ILD	Students discuss and summarize to each other. This discussion also includes other situations in the same concept.
15	ILD steps of worksheet 6	With similar ILDs steps, teacher uses demonstration set B2 and worksheet 6 to teach students on the concept of types of frictional forces.

In brief, lesson plan 3 was based on the ILDs approach. For the others, the designs of lesson plans 1 and 2 were based on the hands-on approach, which focus on doing experiments and discuss each other for the learning. Lesson plan 4 was based on the ILDs approach. When we completely constructed the frictional force learning module comprising (1) demonstration sets, (2) worksheets, (3) lesson plans, and (4) FFCS (as mentioned in the last chapter); this learning module was tried out with Thai high school students and modified to increase the quality.

We have formally used this frictional force learning module with 63 students (70% female) from two classes in Mathayomsuksa 4 in the southern part of Thailand. Two weeks before the beginning of the class, participated students were asked to answer the FFCS as the pre-test. To complete the test, this took of about 30 minutes. After that we asked for permission from the teacher to teach the students on the frictional force topic based on our approach. This process totally took 200 minutes (four periods for a physics class). Then the students were asked to fill out the satisfaction questionnaire to share their comments and suggestion for our frictional force learning module. An example of the questionnaire is shown in Appendix E. Again, two weeks after the end of the class, the students were asked to complete the FFCS as the post-test. The summary of using the learning module in the class is exhibited in Table 4.5.

Table 4.5: Applying the frictional force learning module to the class

Periods	Activities	Time (minutes)
Extra time	**Pre-test**	30
1	**Lesson Plan 1:** Free-body diagram and directions of frictional forces	50
2	**Lesson Plan 2:** Directions of frictional forces (Cont.)	50
3	**Lesson Plan 3:** Types of frictional forces	50
4	**Lesson Plan 4:** Effect factors on the magnitude of frictional forces	50
Extra time	**Post-test**	30

Later, we adjusted the learning module following the students' suggestions. Some demonstration sets were modified to more conveniently use. Worksheets and lesson plans were also corrected in order to fit with Thai high school students and surroundings.

4.3 Summary

This chapter presents how to construct the frictional force learning module based on the hands-on and the Interactive Lecture Demonstrations (ILDs) approaches. This was started form the survey of Thai student prior knowledge on that topic by using the FFCS, and then used the results found as the key resources for designing the module. Our frictional force learning module consists of 4 main components namely (1) 3 demonstration sets (set A, set B, and set C), (2) worksheets, (3) 4 lesson plans, and (4) FFCS. The module was successfully applied to classrooms and modified to reach the proper standard for Thai context. In the next chapter, the last version of the learning module and its effectiveness will be discussed.

CHAPTER V
RESULTS

This chapter reports an effectiveness of the frictional force learning module designed by the researchers. It starts from the presentation of the contexts of participated students. Secondly, we account for the students' responses on the FFCS as the pre- and post-tests. These are explained by the following concepts: directions, types and effect factors on the magnitude of frictional forces. The main statistic values used to describe the results are the t-test and the normalized gain. Lastly, we present the students' satisfaction on the frictional force learning module via the questionnaire.

5.1 Students' Background

Participants (n =293) in this study were selected from two high schools in Bangkok in which the school A (n=160) is a union school and the school B (n=133) is a unisex school for girls. These are 80% female. All of them are about sixteen years old. All are science program students, currently enrolled in the 10^{th} grade (called Mathayomsuksa 4). They have already learned the frictional force concept when they were in the 5^{th} and 9^{th} grades. In the 10^{th} grade, these students are required to learn the frictional force concepts comprising definition of frictional forces, magnitude and direction of frictional forces, types of frictional forces (static and kinetic frictions) by which all focus on the sliding friction in macroscopic scales.

These participants were taught on the topic of the frictional forces via the frictional force learning module by the researcher instead of regular teaching style by their teacher. Total time for studying in this module took 200 minutes. Before the starting, and after the ending of the class for two weeks, the participants were asked to complete the frictional force conceptual survey (FFCS) as the pre- and post-test, respectively. We analyzed the FFCS and reported the results in the following section.

5.2 Results from the Frictonal Force Conceptual Survey: FFCS

FFCS designed by the researchers was used as the assessment tool for evaluation the frictional force learning module. It consists of 20 open-ended items. FFCS has involved three main concepts: 1) directions of frictional forces, 2) types of frictional forces, and 3) effect factors to the magnitude of frictional forces, as shown in Table 5.1. The students' responses to FFCS as the pre- and post-tests are presented by a concept.

Table 5.1: The concept of each item of FFCS

Items	Concepts
1-13	definition of frictional forces (position and direction)
1-13	types of frictional forces (static and kinetic frictions)
14, 18	magnitude of frictional forces (independent of the apparent contact area of the objects)
15, 16, 17	magnitude of frictional forces (independent of the sliding speed of the objects)
19, 20	magnitude of the frictional force (depends on the texture of the object)

5.2.1 The Students' Responses on Concepts of Directions of Frictional Forces

We used items 1-13 of FFCS to find out the students understanding of directions of frictional forces. The percentage of students with correct answer in pre- and post-tests for each item is displayed in Figure 5.1. We have surveyed students understanding of directions of frictional forces as the ground is acting on the object by using Q1-Q3 and Q6 for the horizontal situations, Q4 and Q5 for the vertical situations, Q7 and Q8 for the inclined plane, and Q9-Q13 for the object rotation situations. In Figure 5.1, the pre-test is shown by the white bar and the post-test is shown by the black bar. We found that for all questions the percentages of students with the correct answer in post-test are higher than that in pre-test.

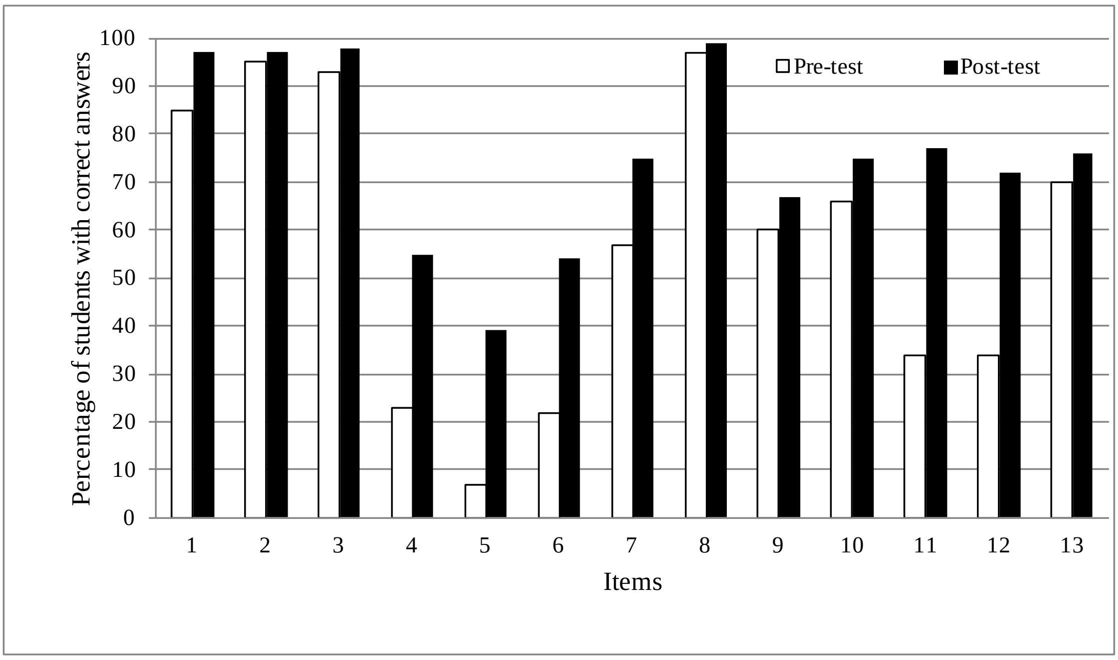


Figure 5.1: The percentages of students with correct answer of the pre- and post-tests for each item regarding the concept of the frictional force direction

In the next section, we will report students' responses in each item that relates to the direction of the frictional force in various situations.

5.2.1.1 Students' responses on the direction of the frictional force in the horizontal situations.

Q1, Q2, Q3 and Q6 of FFCS asked students to draw the arrows representing the frictional force direction that the ground acts on the object in various horizontal situations. Table 5.2 shows the percentages of students, who answered Q1, Q2, Q3, and Q6 in the pre-and post-tests, with different directions such as Left Direction (*Left Dirt.*), Right Direction (*Right Dirt.*), Upward Direction (*Up Dirt.*), Downward Direction (*Down Dirt.*), and No Direction (*No Dirt.*). The shaded cell in the table shows the correct answer of each situation.

Table 5.2 Students' responses on Q1, Q2, Q3, and Q6 concerning the concept of the frictional force direction in the horizontal situations

The Items of Horizontal Situations			%Students' Responses on the Direction of the Frictional Force				
			Left Dirt.	*Right Dirt.*	*Up Dirt.*	*Down Dirt.*	*No Dirt.*
Q1	Stationary 	**Pre-test (n=211)**	**-**	**9%**	**2%**	**4%**	**85%**
		Post-test (n=293)	**1%**	**1%**	**1%**	**-**	**97%**
Q2	Stationary 	**Pre-test (n=226)**	**5%**	**95%**	**-**	**-**	**-**
		Post-test (n=293)	**2%**	**97%**	**-**	**-**	**1%**
Q3	The constant speed 	**Pre-test (n=246)**	**7%**	**93%**	**-**	**-**	**-**
		Post-test (n=293)	**2%**	**98%**	**-**	**-**	**-**
Q6		**Pre-test (n=211)**	**72%**	**22%**	**-**	**3%**	**3%**
		Post-test (n=293)	**41%**	**54%**	**2%**	**-**	**3%**

For Q1, the situation is that a kettle rests on the rough surface. The students were asked to determine the direction of the frictional force by which the ground acts on the kettle. Since there is no external force parallel to the surface, the frictional force does not exist. Result shows 85% and 97% of students with correct answer (*No Dirt.*) in the pre-and post-tests, respectively.

For Q2, the situation is that the kettle is pushed but still stationary. The students were asked to determine the direction of the frictional force by

which the ground acts on the kettle. The correct answer is that the direction of the frictional force acting by the ground on the kettle points to the right hand side.
Result shows 95% and 97% of students with correct answer (*Right Dirt*.) in the pre-and post-tests, respectively.

For Q3, the situation is that the kettle is pushed and then moved from right to left hand side with the constant speed. The students were asked to determine the direction of the frictional force by which the ground acts on the kettle.
The correct answer is that the direction of the frictional force acting by the ground on the kettle points to the right hand side. Result shows 93% and 98% of students with correct answer (*Right Dirt*.) in the pre-and post-tests, respectively.

For Q6, the situation is that a soccer player is running without skidding to a ball from left to right hand side. The students were asked to determine the direction of the frictional force acting by the ground on the foot of the player. The correct answer is that the direction of the frictional force by which the ground acts on the foot of the player points to the right hand side. We found only 22% of the participants with correct answer (*Right Dirt*.) in the pre-test. But most students (72%) believed that it points to the left hand side. After the ending of our frictional force learning module, results showed 54% of students with the correct answer. This is much possible that the higher percentage of students with correct answer in the post-test was come from the students, who held the alternative concept in the pre-test. Clearly, the students have changed their ideas after the learning by using this module.

5.2.1.2 Students' responses on the direction of the frictional force in the vertical situations.

Q4 and Q5 of FFCS asked students to draw the arrows representing the frictional force direction that the thumb acts on the glass surface in various vertical situations. Table 5.3 shows the percentages of students, who answered Q4 and Q5 in the pre-and post-tests, with different directions such as Left Direction (*Left Dirt.*), Right Direction (*Right Dirt.*), Upward Direction (*Up Dirt.*), Downward Direction (*Down Dirt.*), and No Direction (*No Dirt.*). The shaded cell in the table shows the correct answer of each situation.

Table 5.3 Students' responses on Q4 and Q5 concerning the concept of the frictional force direction in the vertical situations

The Items of Vertical Situations		%Students' Responses on the Direction of the Frictional Force				
		Left Dirt.	*Right Dirt.*	*Up Dirt.*	*Down Dirt.*	*No Dirt.*
Q4 	**Pre-test (n=282)**	**-**	**4%**	**23%**	**26%**	**47%**
	Post-test (n=293)	**-**	**-**	**55%**	**12%**	**33%**
Q5 **The constant velocity** 	**Pre-test (n=217)**	**-**	**1%**	**7%**	**85%**	**7%**
	Post-test (n=293)	**-**	**-**	**39%**	**55%**	**6%**

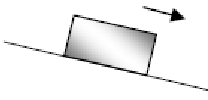
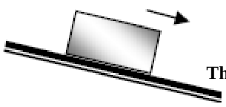
For Q4, the situation is that a woman still holds a glass in the air. The students were asked to determine the direction of the frictional force by which the thumb acts on the glass surface. The frictional force exists between the thumb and the glass surface to resist the weight of that glass. Therefore, the direction of the frictional force acting by the thumb on the glass surface points to upward direction. Results showed only 23% of the participants with correct answer (*Up Dirt*.) in the pre-test. But most (47%) believed that there is no frictional force, no direction as well. After the teaching and learning, it displayed 55% of students with correct answer as the post-test.

For Q5, the situation is that the woman is lifting up the glass with the constant velocity and no sliding. The students were asked to determine the direction of the frictional force by which the thumb acts on the glass surface. The correct answer is that the direction of the frictional force acting by the thumb on the glass surface points to upward direction. We found only 7% of the students with correct answer (*Up Dirt*.) in the pre-test. These changed to 39% in the post-test. However, most still believed that since the glass is moving up; the direction of the frictional force points downward.

5.2.1.3 Students' responses on the direction of the frictional force in the inclined situations.

Q7 and Q8 of FFCS asked students to draw the arrows representing the frictional force direction that the inclined plane acts on the box in various inclined situations. Table 5.4 shows the percentages of students, who answered Q7 and Q8 in the pre-and post-tests, with different directions such as Rear Direction *(Rear Dirt.),* Front Direction *(Front Dirt.),* Upward Direction (*Up Dirt.*), Downward Direction (*Down Dirt.*), and No Direction (*No Dirt.*). The shaded cell in the table shows the correct answer of each situation.

Table 5.4 Students' responses on Q7 and Q8 concerning the concept of the frictional force direction in the inclined situations

The Items of Inclined Situations		%Students' Responses on the Direction of the Frictional Force				
		Rear Dirt.	*Front Dirt.*	*Up Dirt.*	*Down Dirt.*	*No Dirt.*
Q7 	**Pre-test (n=243)**	**39%**	**4%**	**-**	**-**	**57%**
	Post-test (n=293)	**24%**	**1%**	**-**	**-**	**75%**
Q8 	**Pre-test (n=249)**	**97%**	**3%**	**-**	**-**	**-**
	Post-test (n=293)	**99%**	**1%**	**-**	**-**	**-**

For Q7, the situation is that a box is sliding downward on the slippery inclined plane. The students were asked to determine the direction of the frictional force by which the inclined plane acts on the box. Because it is the slippery inclined plane, which refers to the frictionless, there is no friction between the inclined plane and the box. Results showed 57% and 75% of students with correct answer (*No Dirt.*) in the pre-and post-tests, respectively. Some believed there was the frictional force acting by the inclined plane on the box in the rear direction.

For Q8, the situation is that the box is sliding downward on the rough inclined plane. The students were asked to determine the direction of the frictional force by which the inclined plane acts on the box. In this situation, the weight of the box in the direction of the inclined plane makes the box slides so the frictional force exists between the surfaces of the inclined plane and the box. The frictional force direction acting by the plane on the box points rearward.

We found 97% and 99% of students with correct answer (*Rear Dirt.)* in the pre-and post-tests, respectively. However, most gave the major reason that the box is moving downward so the frictional force points to the rear direction. They believed that the frictional force is always opposite to the direction of the object movement.

5.2.1.4 Students' responses on the direction of the frictional force in the situations of the object rotation

Q9-Q13 of FFCS asked students to draw the arrows representing the frictional force direction that the ground acts on the object in various situations of the object rotation. Table 5.5 shows the percentages of students, who answered Q9-Q13 in the pre-and post-tests, with different directions such as Rear Direction *(Rear Dirt.)*, Front Direction *(Front Dirt.)*, Upward Direction (*Up Dirt.*), Downward Direction (*Down Dirt.*), and No Direction (*No Dirt.*). The shaded cell in the table shows the correct answer of each situation.

Table 5.5 Students' responses on Q9, Q10, Q11, Q12, and Q13 concerning the concept of the frictional force direction in case of the object rotation

The Items of the Object Rotation Situations			%Students' Responses on the Direction of the Frictional Force				
			Rear Dirt.	*Front Dirt.*	*Up Dirt.*	*Down Dirt.*	*No Dirt.*
Q9 		**Pre-test (n=235)**	**60%**	**37%**	**-**	**-**	**3%**
		Post-test (n=293)	**67%**	**33%**	**-**	**-**	**-**
	**Q10** Ground acts on the front wheel	**Pre-test (n=214)**	**66%**	**34%**	**-**	**-**	**-**
		Post-test (n=293)	**75%**	**24%**	**-**	**-**	**1%**
	Q11 Ground acts on the rear wheel	**Pre-test (n=214)**	**64%**	**34%**	**-**	**2%**	**-**
		Post-test (n=293)	**23%**	**77%**	**-**	**-**	**-**
	**Q12** Ground acts on the front wheel	**Pre-test (n=217)**	**66%**	**34%**	**-**	**-**	**-**
		Post-test (n=293)	**28%**	**72%**	**-**	**-**	**-**
	Q13 Ground acts on the rear wheel	**Pre-test (n=211)**	**70%**	**28%**	**-**	**-**	**2%**
		Post-test (n=293)	**76%**	**23%**	**-**	**-**	**1%**

For Q9, the situation is that a man pushing a cart from right to left hand side without skidding between the ground and the cart' s wheels. The students were asked to determine the direction of the frictional force by which the ground acts on the cart's wheels. In this situation, the cart's wheels are counterclockwise rotated by the frictional force pointing to the rear direction. Results showed 60% and 67% of students with correct answer (*Rear Dirt.*) in the pre-and post-tests, respectively. However, most gave the major reason that the cart is moving forward so the frictional force points to the rear direction. They believed that the frictional force is always opposite to the object movement.

For Q10 and Q11, the situation is that a man is riding the bicycle, driven by the rear wheel, uphill with increasing velocity. The students were asked to determine the direction of the frictional force by which the ground acts on the front wheel for Q10 and the ground acts on the rear wheel for Q11. In this situation, the front wheel of the bicycle is clockwise rotated by the frictional force pointing to the rear direction. In contrast, the rear wheel is pedaled by the rider's feet to rotate. This makes the body of the bicycle move forward. Therefore, the frictional force direction acting by the ground on the rear wheel of the bicycle points to the front direction. We found 66% and 75% of students with correct answer (*Rear Dirt.*) in the pre-and post-tests of Q10, respectively. For Q11, we found 34% and 77% of students with correct answer (*Front Dirt.*) in the pre-and post-tests, respectively.

For Q12 and Q13, the situation is that a boy is riding a tricycle, driven by the front wheel, from left to right hand side. The students were asked to determine the direction of the frictional force by which the ground acts on the front wheels for Q12 and the ground acts on the rear wheel for Q13. The correct answer of Q12 is that the frictional force direction acting by the ground on the front wheels points forward. The correct answer of Q13 is that the frictional force direction acting by the ground on the rear wheel points rearward. Results showed 34% and 72% of students with correct answer (*Front Dirt.*) in the pre-and post-tests of Q12, respectively. For Q13, we found 70% and 76% of students with correct answer (*Rear Dirt.*) in the pre-and post-tests, respectively.

5.2.2 The Students' Responses on Concepts of Types of Frictional Forces

We also used items 1-13 of FFCS to survey the students understanding of types of frictional forces. The percentage of students with correct answer in pre- and post-tests for each item is displayed in Figure 5.2. Similarly to the former section, we reported the students' responses by grouping into the horizontal situations (Q1-Q3 and

Q6), the vertical situations (Q4-Q5), the inclined plane situations (Q7-Q8), and the object rotation situations (Q9 and Q10-Q13). In Figure 5.2, the pre-test is shown by the white bar and the post-test is shown by the black bar. We found that for all questions the percentages of students with the correct answers in post-test are higher than that in pre-test.

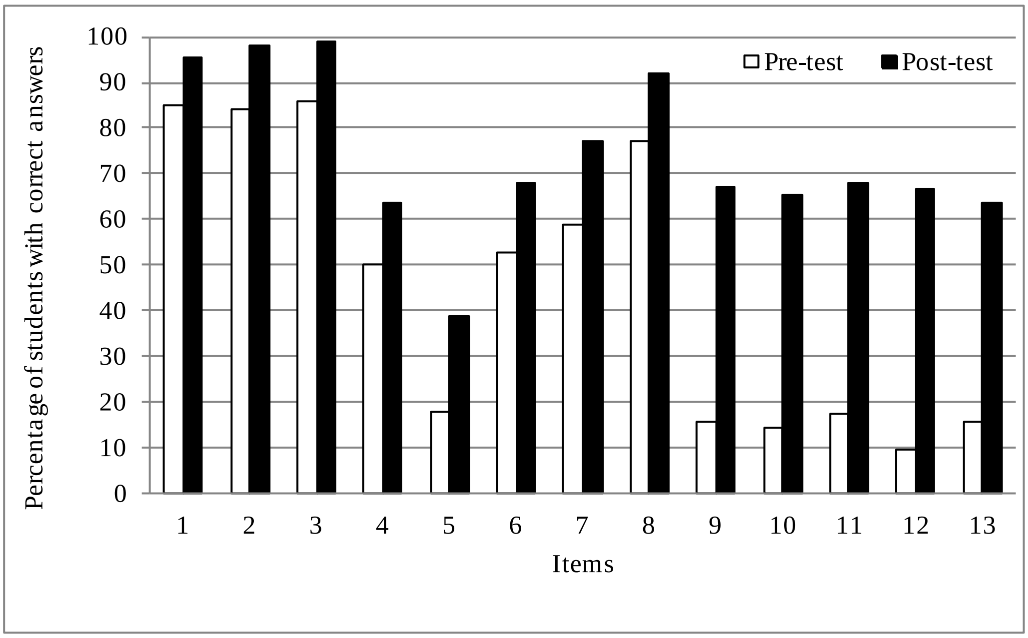


Figure 5.2: The percentages of students with correct answers of the pre- and post-tests for each item regarding the concept of the frictional force types

In the next section, we will report students' responses in each item that relates to the types of the frictional force in various situations.

5.2.2.1 Students' responses on the types of frictional forces in the horizontal situations

Q1, Q2, Q3 and Q6 of FFCS asked students to mark the type of frictional forces in terms of Static Friction (*Static Frict.*), Kinetic Friction (*Kinetic Frict.*), or No Friction (*No Frict.*) in various horizontal situations. Table 5.6 shows the percentages of students, who answered Q1, Q2, Q3, and Q6 in the pre-and post-tests. The shaded cell in the table shows the correct answer of each situation.

Table 5.6 Students' responses on Q1, Q2, Q3, and Q6 regarding the concept of the frictional force types in the horizontal situation

The Items of Horizontal Situations			%Students' Responses on the Type of the Frictional Force		
			Static Frict.	*Kinetic Frict.*	*No Frict.*
Q1	**Stationary** 	**Pre-test (n=273)**	**13%**	**2%**	**85%**
		Post-test (n=293)	**4%**	**-**	**96%**
Q2	**Stationary** 	**Pre-test (n=273)**	**84%**	**13%**	**3%**
		Post-test (n=293)	**98%**	**1%**	**1%**
Q3	**The constant speed** 	**Pre-test (n=293)**	**12%**	**87%**	**1%**
		Post-test (n=293)	**1%**	**99%**	**-**
Q6		**Pre-test (n=287)**	**53%**	**43%**	**4%**
		Post-test (n=293)	**78%**	**20%**	**2%**

For Q1—the kettle rests on the horizontal surface; since there is no parallel force to the surface, there is no the frictional force. We found that most students can correctly answer this question in pre-test (85%) and post-test (96%).

For Q2—the kettle is pushed but still stationary; the static friction exists between the ground and its bottom. Results showed 84% and 98% of students with correct answer in the pre-and post-tests, respectively.

For Q3— the kettle is moved on the rough surface; the kinetic friction exists between the ground and its bottom. We found that 87% and 99% of students can correctly answer this item in the pre-and post-tests, respectively.

For Q6—the soccer player is running without skidding; the static friction exists between the player’s feet and the ground. Results showed 53% and 78% of students with correct answer in the pre-and post-tests, respectively

5.2.2.2 Students’ responses on the types of frictional forces in the vertical situations

Q4 and Q5 of FFCS asked students to mark the type of frictional forces in terms of Static Friction (*Static Frict.*), Kinetic Friction (*Kinetic Frict.*), or No Friction (*No Frict.*) in various vertical situations. Table 5.7 shows the percentages of students, who answered Q4 and Q5 in the pre-and post-tests. The shaded cell in the table shows the correct answer of each situation.

Table 5.7 Students’ responses on Q4, and Q5 regarding the concept of the frictional force types in the vertical situations

The Items of Vertical Situations		%Students’ Responses on the Type of the Frictional Force		
		Static Frict.	*Kinetic Frict.*	*No Frict.*
Q4 	**Pre-test (n=293)**	**50%**	**3%**	**47%**
	Post-test (n=293)	**65%**	**2%**	**33%**
Q5 	**Pre-test (n=293)**	**18%**	**70%**	**12%**
	Post-test (n=293)	**39%**	**57%**	**4%**

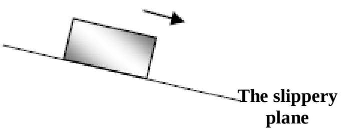
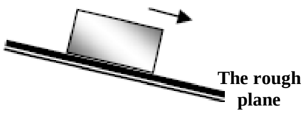
For Q4—a woman holds a stationary glass in the air; the static friction exists between the woman's thumb and the glass's surface. We found that 50% and 65% of students can correctly answer this item in the pre-and post-tests, respectively.

For Q5—the woman is lifting up the glass with the constant velocity and no sliding; the static friction exists between the woman's thumb and the glass's surface. Results showed 18% and 39% of students with correct answer in the pre-and post-tests, respectively. Most believed that the kinetic friction involved in this situation because the glass is moving.

5.2.2.4 Students' responses on the types of frictional forces in the inclined situations

Q7 and Q8 of FFCS asked students to mark the type of frictional forces in terms of Static Friction (*Static Frict.*), Kinetic Friction (*Kinetic Frict.*), or No Friction (*No Frict.*) in various inclined situations. Table 5.8 shows the percentages of students, who answered Q7 and Q8 in the pre-and post-tests. The shaded cell in the table shows the correct answer of each situation.

Table 5.8 Students' responses on Q7 and Q8 regarding the concept of the frictional force types in the inclined situations

The Items of Inclined Situations		**%Students' Responses on the Type of the Frictional Force**		
		Static Frict.	***Kinetic Frict.***	***No Frict.***
Q7 	**Pre-test (n=293)**	**6%**	**35%**	**59%**
	Post-test (n=293)	**1%**	**22%**	**77%**
Q8 	**Pre-test (n=293)**	**22%**	**77%**	**1%**
	Post-test (n=293)	**7%**	**92%**	**1%**

For Q7— a box is sliding downward along the slippery inclined plane; there is no frictional force between the box and the plane. We found that 59% and 67% of students can correctly answer this item in the pre-and post-tests, respectively.

For Q8—a box is sliding downward along the rough inclined plane; the kinetic friction exists between the box and the plane. We found that 77% and 92% of students can correctly answer this item in the pre- and post-tests, respectively.

5.2.2.5 Students' responses on the types of frictional forces in the situations of the object rotation

Q9-Q13 of FFCS asked students to mark the type of frictional forces in the term of Static Friction (*Static Frict.*), Kinetic Friction (*Kinetic Frict.*), or No Friction (*No Frict.*) in various situations of the object rotation. Table 5.9 shows the percentages of students, who answered Q9-Q13 in the pre-and post-tests. The shaded cell in the table shows the correct answer of each situation.

Table 5.9 Students' responses on Q9-Q13 regarding the concept of the frictional force types in situations of the object rotation

The Situations of the Object Rotation			%Students' Responses on the Type of the Frictional Force		
			Static Frict.	*Kinetic Frict.*	*No Frict.*
Q9 		**Pre-test (n=293)**	**16%**	**82%**	**2%**
		Post-test (n=293)	**67%**	**33%**	**-**
	**Q10** Ground acts on the front wheel	**Pre-test (n=287)**	**14%**	**82%**	**4%**
		Post-test (n=293)	**66%**	**33%**	**-**
	Q11 Ground acts on the rear wheel	**Pre-test (n=287)**	**18%**	**79%**	**3%**
		Post-test (n=293)	**68%**	**32%**	**-**
	**Q12** Ground acts on the front wheel	**Pre-test (n=287)**	**10%**	**87%**	**3%**
		Post-test (n=293)	**67%**	**33%**	**-**
	Q13 Ground acts on the rear wheel	**Pre-test (n=287)**	**16%**	**80%**	**4%**
		Post-test (n=293)	**64%**	**34%**	**2%**

Q9-Q13 involves the rotation of the wheel without skidding on the ground. Students were asked to mark the type of frictional force existing between the wheel and the ground. Clearly, the object is rotated without skidding; the static friction exists. We found 10%-18% of students with correct answer in the pre-test. But in the post-test after the learning by using our leaning module, these have increased to 64%-68%.

5.2.3 The Students' Responses on the Concept of the Effect Factors on the Magnitude of the Frictional Force

We used items 14-20 of FFCS to examine the students understanding of effect factors on the magnitude of the frictional force. The percentage of students with correct answer in pre- and post-tests for each item is displayed in Figure 5.3. These were divided into 3 groups: (1) Q14 and Q18 for the concept that the magnitude of the frictional force is independent of apparent contact area of the object; (2) Q15-Q17 for the concept that the magnitude of the frictional force is independent of the sliding speed of the object; and (3) Q19 and Q20 for the concept that the magnitude of the frictional force depends on the material of the object. In Figure 5.3, the pre-test is shown by the white bar and the post-test is shown by the black bar. We found that for all questions the percentages of students with the correct answer in post-test are higher than that in pre-test.

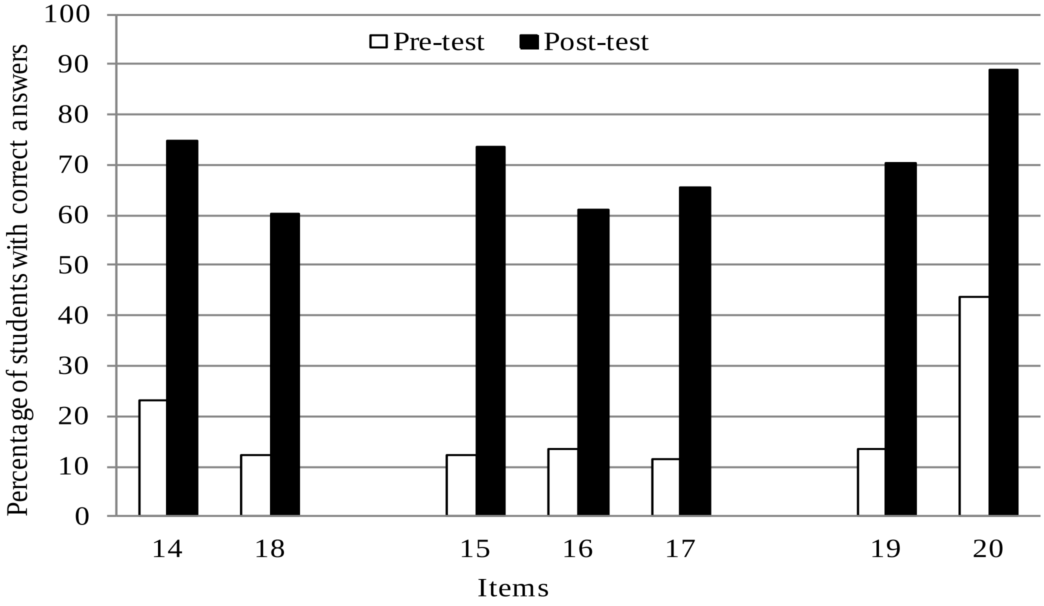


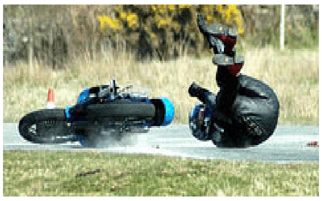
Figure 5.3: The percentages of students (n=293) with correct answer for eight items about the effect factors to the magnitude of the frictional force

In the next section, we will report students' responses in each item that relates to the magnitude of the frictional force, as grouped by 3 main concepts.

5.2.3.1 The magnitude of the frictional force is independent of apparent contact area of the object

Q14 and Q18 of FFCS asked students to write their answers and give reasons for a given situation regarding the independent of magnitude of frictional force on the size of contact area. We read the students explanations for each item and categorized into 4 groups by the idea as shown in table 5.10. These consist of: (a) the correct idea as displayed by the shaded cell; (b) the major misconception with some examples of students' explanations; (c) other irrelevant ideas; and (d) no idea or without the explanations. The percentage of students with each group in the pre-and post-tests is disclosed in the last two columns of the table.

Table 5.10 Students' responses on Q14 and Q18

<table>
<tr><th rowspan="2">Items</th><th rowspan="2">Students' Ideas</th><th colspan="2">Students' Responses</th></tr>
<tr><th>Pre-test (n=293)</th><th>Post-test (n=293)</th></tr>
<tr><td rowspan="2">Q14

Situation: A motorist had an accident. He slid on his back along the road surface. The frictional force between his back and the ground existed. Question: If the motorist slides on his side, does the magnitude of the frictional force during the sliding on his back differ from that on his side along the road surface? Why?</td><td>a) NO. The magnitude of frictional forces is independent of the size of the contact area. / The back and side of the motorist's wear were made of the same material; so the frictional force magnitudes are equal for both situations.</td><td>12%</td><td>74%</td></tr>
<tr><td>b) The magnitude of frictional forces depends on the size of contact area. Examples of students' explanations;
-YES. The contact area between his back and the ground is larger than that between his side and the ground, so it generates more magnitude of the frictional force.
-YES. The larger area of his back occupied more weight than that of the lesser area of his side, so it generates more magnitude of the frictional force.</td><td>55%</td><td>12%</td></tr>
</table>

	c) *Other ideas (e.g. NO. Both are equal because they are the same type of frictional forces)*	6%	4%
	d) *No idea*	17%	-
Q18   **Situation:** A man taken the rubber gloves holds a water glass in two different styles; (1) holding by using three fingers; and (2) holding by using five fingers. **Question:** Do the magnitudes of frictional forces between the fingers and the glass surface equally exist for both styles? Why?	a) *YES. The magnitude of frictional forces is independent of the size of the contact area. / The gloves were made of the same rubber (the glass was made of the same material); so the frictional force magnitudes are equal for both cases.*	**12%**	**60%**
	b) *The magnitude of frictional forces depends on the size of contact area. An examples of students' explanation;* *- NO. The contact area between five fingers and the glass is larger than that between three fingers and the glass, so it generates more magnitude of the frictional force.*	62%	34%
	c) *Other ideas (e.g. YES. There no frictional force; YES. They used the same speed of glass moving so the same magnitude of frictional force exists.*	3%	6%
	d) *No ideas*	23%	-

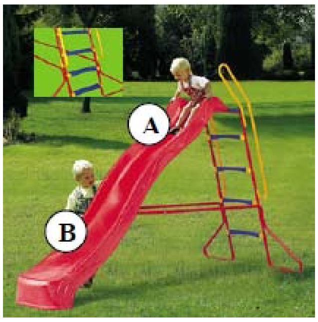
For Q14 and Q18, we found very similar responses. There are many students having alternative concepts in the pre-test, but these are reduced after learning by using our learning module shown in the post-test. There are 74% (Q14) and 60% (Q18) of students with correct explanation that the magnitude of frictional forces is independent of the size of the contact area. Moreover, we also found a group of students who did not responses any reason in the pre-test (17% for Q14 and 23% for Q18). But all shared their idea in the post-test. Although we did not clearly know what they thought in the pre-test, it is much possible that they hold the correct idea in the post-test of the Table 5.10.

5.2.3.2 The magnitude of the frictional force is independent of the sliding speed of the object

Q15-Q17 of FFCS asked students to write their answer and give reason for a given situation regarding the independent of magnitude of frictional force on the sliding speed of the object. We grouped students' responses and showed in Table 5.11. The shaded cell in the table shows the correct answer of each situation.

Table 5.11 Students' responses on Q15, Q16, and Q17

Items	Students' Ideas	Students' Responses	
		Pre-test (n=293)	Post-test (n=293)
Q15  **Situation:** An elephant is pulling a lumber placed on solid ground. The frictional force between the ground and the lumber exists. **Question:** If the elephant pulls the lumber to slide with two different constant speeds, do the frictional force magnitudes between the ground and the lumber equally exist? Why?	a) *YES. The magnitude of frictional forces is independent of the sliding speed of the lumber. / These are the same lumber (same mass and same material) and same ground; so the magnitudes of frictional force are the same for both situations.*	**12%**	**73%**
	b) *The magnitude of frictional forces depends on the sliding speed of the lumber. Examples of students' explanations;* *- NO. The faster moving lumber generates a lower magnitude of frictional force between the ground and the lumber. The lumber is pulled faster because of having lesser frictional force existing to resist its movement.* *-NO. The faster moving lumber generates the higher magnitude of frictional force existing between the ground and the lumber. Because the lumber is pulled faster by a higher force. This makes higher frictional force, as well.*	73%	23%
	c) *Other ideas (e.g. NO. They are different movement, so different magnitudes of frictional forces exist)*	8%	3%
	d) *No idea*	7%	1%

Q16  **Situation:** a worker is pushing a cabinet to slide on the ground with a constant speed. **Question:** If he pushes the cabinet to slide on the ground with twice constant speed of the former. Do the frictional force magnitudes between the ground and the cabinet of the both situations equally exist? Why?	a) *YES. The magnitude of frictional forces is independent of the sliding speed of the cabinet. / These are the same cabinet (same mass and same material) and same ground; so the magnitudes of frictional force are the same for both.*	**9%**	**74%**
	b) *The magnitude of frictional forces depends on the sliding speed of the cabinet. Examples of students' explanations;* *-NO. The cabinet has different speeds due to the different magnitudes of frictional force existing to resist the push force.* *-NO. The faster cabinet requires a more push force, so it generates more magnitude of frictional force.*	59%	23%
	c) *Other ideas (e.g. YES. Both generate the same type of frictional forces.)*	5%	3%
	d) *No idea*	7%	
Q17  **Situation:** A child is sliding down on a slide. **Question:** While he is sliding through position A (the upper position of the slide) and position B (the lower position of the slide), do the frictional force magnitudes between the child and the slide at position A and B equally exist? Why?	a) *YES. The magnitude of frictional forces is independent of the sliding speed of the child. / These are the same child (same mass) and same material of the slide; so the magnitudes of frictional force are the same for both cases.*	**11%**	**66%**
	b) *The magnitude of frictional forces depends on the sliding speed of the child. An example of students' explanations;* *-NO. Since there is more slope at B position that makes more speed of the child, the magnitude of frictional forces at this position is more than at A position.*	65%	25%
	c) *Other ideas (e.g. NO. they generate different types of frictional forces.)*	8%	7%
	d) *No idea*	16%	2%

For Q15-Q17, we found 59%-73% of students, who believed that the magnitude of frictional forces depends on the sliding speed of the object. It is an incorrect idea for these three situations. These are changed to 23%-25% in the post-test.

5.2.3.3 The magnitude of the frictional force depends on the material of the object

Q19-Q20 of FFCS asked students to write their answer and give reason for a given situation regarding the dependent of magnitude of frictional force on material of the object. The students' responses were grouped into 3 main clusters: (a) correct idea, (b) incorrect idea, and (c) no idea or no explanation. The percentage of students for each situation in the pre-and post-tests are shown in the last two columns in Table 5.12. The shaded cell in the table shows the correct answer of each situation.

Table 5.12 Students' responses on Q19 and Q20

Items	Students' Ideas	Students' Responses	
		Pre-test (n=293)	Post-test (n=293)
Q19  **Situation:** A wardrobe is pushed to move on the concrete floor by a woman. **Question:** Instead of the woman, if this wardrobe is pushed by a man with the same movement, do the frictional force magnitudes between the wardrobe and the concrete floor for both equally exist? Why?	a) *YES. The magnitude of the frictional force depends on the surface roughness of the floor./ They are the same wardrobe, floor, and mass, so the frictional force magnitudes are equal.*	**13%**	**70%**
	b) *NO. The wardrobe is pushed to move with the different forces, so the different frictional forces exist.*	65%	27%
	c) *No idea*	22%	3%

Q20  **Situation:** An acrylic and a glass plates with the same weight and size, are placed and pulled by the constant speed on the table. **Question:** Do the frictional force magnitudes of the acrylic plate and the table, and the glass and the table equally exist? Why?	a) *NO. The magnitude of the frictional force depends on the surface roughness of the floor./ They are different materials, so the frictional force magnitudes differ.*	**44%**	**89%**
	b) *YES. They have same weight, size of contact area, and speed, so the frictional force magnitudes are the same values.*	40%	10%
	c) *No idea*	16%	3%

For Q19, we found 65% of students in the pre-test, who believed that the frictional force magnitude in this situation depends on the push force. In fact, we consider the situation while the wardrobe is moving. This exclusively involves the kinetic friction. The magnitude of kinetic friction doesn't involve with the push force. For Q20, results showed 44% of students with the correct explanation that the frictional force magnitude depends on the material of the object in the pre-test. These increase to 89% in the post-test.

In addition, we calculated the statistical values of the FFCS such as the pre-test mean score (M_{pre}), post-test mean score (M_{post}), the standard deviations of the pre-and post-tests (SD_{pre}, SD_{post}), the t-test (*t-value, Sig.(one-tailed)*), and the average of the normalized gain (<**g**>) of each concept of the frictional force, as shown in Table 5.13.

The Table 5.13 shows the statistical values related to the concept of the frictional force direction (Q1-Q13); the types of frictional forces (Q1-Q13); and the effect factors on the frictional force magnitude namely the size of the apparent contact area (Q14 and Q18) as labeled "E_1", the sliding speed of the object (Q15-Q17) as labeled "E_2" and the roughness surface of the object (Q19 and Q20) as labeled "E_3".

All the results revealed that the post-test mean score (M_{post}) was greater than the pre-test mean score (M_{pre}), proved by the paired t-test at 0.01 significant level. Moreover, we calculated the students' overall improvement for each concept via the average of the normalized gain (<**g**>) as shown in the last column. We found the medium learning gain (**0.3 ≤ <g> ≤ 0.7**) of these students for all concepts after the learning by using our frictional force learning module.

Table 5.13: The statistical values of the FFCS separated by concept: directions of frictional forces, types of frictional forces, and effect factors on the frictional force magnitude for participants from schools A and B with the t-test and the normalized gain

Concepts		*Statistics*						
		M_{pre}	SD_{pre}	M_{post}	SD_{post}	*t-value*	**Sig.* *(one-tailed)*	<g>
Directions of frictional forces (n=211)		**5.56**	**2.49**	**9.18**	**1.05**	**21.45**	**<0.01**	**0.49**
Types of frictional forces (n=273)		**4.56**	**1.73**	**9.60**	**2.24**	**33.16**	**<0.01**	**0.59**
Effect factors on the frictional force magnitude (n=293)	E_1	**0.35**	**0.64**	**1.35**	**0.76**	**20.16**	**<0.01**	**0.61**
	E_2	**0.43**	**0.79**	**2.14**	**1.17**	**23.72**	**<0.01**	**0.66**
	E_3	**0.57**	**0.64**	**1.59**	**0.60**	**21.45**	**<0.01**	**0.72**

*We considered at the 99% confidence interval of the difference.

5.3 The Results from the Satisfaction Questionnaire

We evaluated students' satisfaction on these learning modules by using the satisfaction questionnaire. The questionnaire was composed of 5 items with 5 levels of the Likert scales. The Likert scales were divided as 1 (strongly disagree), 2 (disagree), 3 (fair), 4 (agree) and 5 (strongly agree). Students were free to select a scale for an item. The satisfaction questionnaire was provided in Appendix E. Students took around 5-10 minutes to fill out this document after the finishing of the class. The items of this satisfaction questionnaire were analyzed to find what students thought about our learning module, as shown in Figure 5.4.

In Figure 5.4, we plotted the 5 items of the satisfaction questionnaire (y-axis) and the percent totals of students, who selected 4 (agree) and 5 (strongly agree) for each item (x-axis). Results (n=293) exposed that more than 90% of these students agreed/ strongly agreed that this learning module help them to learn the concepts of the frictional force. In general, most students preferred the demonstrations in this module, shown in item 1, to the others. Most thought this module strongly related to everyday life situations (item 5), provided the useful prediction sheets in the demonstration sets (item 2), enhanced to predict events before the actual demonstration (item 4), and gave opportunities to share ideas with peers (item3).

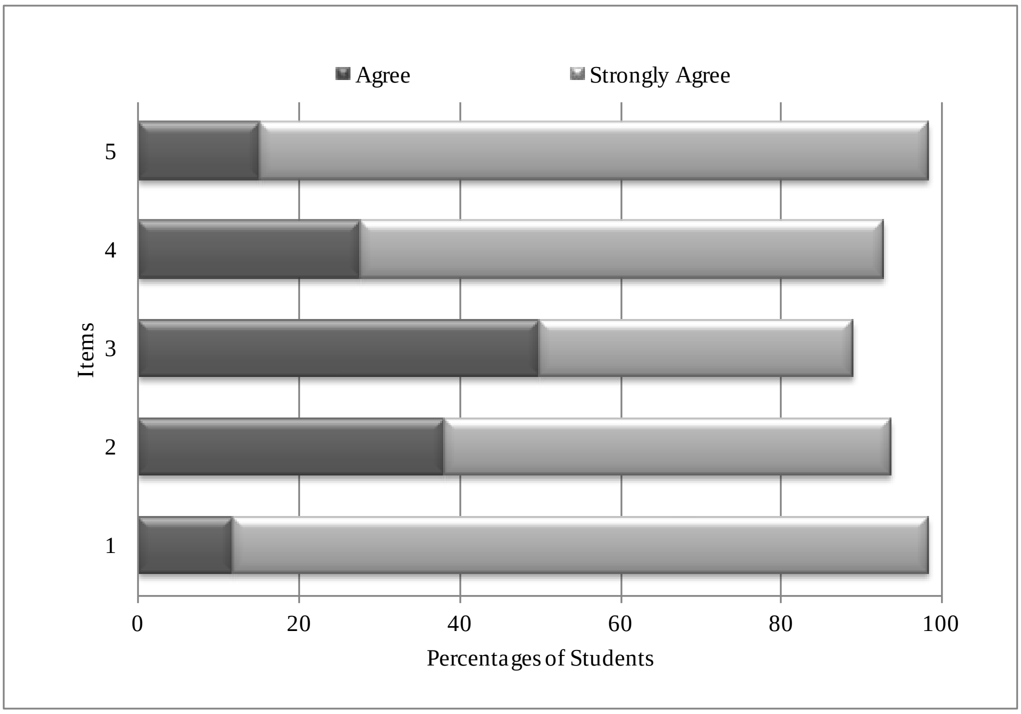


Figure 5.4: The percentage of students (n=293), who selected agree (4) and strongly agree (5) for the 5 Likert scale items of the satisfaction questionnaire.

5.4 Summary

In this study, after our frictional force learning module based on the hands-on and ILDs approaches was developed to succeed the statistically reliable learning tools, it was used with Thai students (n=293) in Mathayomsuksa 4. After the instruction, we evaluated students' learning gain by using the Frictional Force Conceptual Survey (FFCS), including students' satisfaction by using the satisfaction questionnaire. Findings revealed that the instruction by using our learning module, in particular, for concepts of the frictional force direction, the frictional force type, and the effect factors on the sliding frictional force, facilitated students' learning into the average medium gain, justified by the normalized gain. Moreover, most students agreed that this learning module help them to learn about the concepts of the frictional force.

CHAPTER VI
DISCUSSION

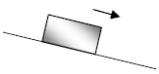
In the discussion part, we will consider the learning gain (**<g>**) of students after using the frictional force learning module. The students' learning gain is identified by the pre- and post-tests from the FFCS in the concepts of the frictional force comprising the direction and the type of frictional forces and the effect factors on the frictional force magnitude in various situations.

6.1 Students' Learning Regarding the Direction of the Frictional Force

The learning gain has been classified in three levels— high gain when the value is more than 0.7, medium gain when the value is between 0.7 and 0.3, as well as low gain when the value is less than 0.3 (Hake,1998). In this section, we report the students' learning gain and discuss the students' responses on the FFCS about the direction of the frictional force in the horizontal, vertical, and inclined situations as well as the situation of the object rotation.

The frictional force learning module for the direction of the frictional force is administered by the learning process of the hands-on approach. Overall, the result in Table 6.1 shows that this learning module can help students to improve the understanding in the medium gain. The results correspond to results presented by many researchers (Meyers & Jones, 1993; Sokoloff & Thornton, 1997; Hack, 1998; Lalley & Miller, 2007). This mainly reveals that whenever the students are instructed by the active learning process the learning gain obtained will be higher than 0.3.

Table 6.1: The percentage of students with correct answer of pre- and post-tests and students' learning gain regarding the frictional force directions in various situations

The Items		% Students with Correct Answer	Learning Gain (<g>)
The horizontal situation			
Q1 Stationary 	**Pre-test (n=211)**	**85%**	**0.80**
	Post-test (n=293)	**97%**	
Q2 Stationary 	**Pre-test (n=226)**	**95%**	**0.40**
	Post-test (n=293)	**97%**	
Q3 The constant speed 	**Pre-test (n=246)**	**93%**	**0.71**
	Post-test (n=293)	**98%**	
Q6 	**Pre-test (n=211)**	**22%**	**0.41**
	Post-test (n=293)	**54%**	
The vertical situation			
Q4 	**Pre-test (n=282)**	**23%**	**0.42**
	Post-test (n=293)	**55%**	
Q5 The constant velocity 	**Pre-test (n=217)**	**7%**	**0.34**
	Post-test (n=293)	**39%**	
The inclined situation			
Q7 	**Pre-test (n=243)**	**57%**	**0.42**
	Post-test (n=293)	**75%**	
Q8 	**Pre-test (n=282)**	**97%**	**0.67**
	Post-test (n=293)	**99%**	

The situations of the object rotation				
Q9 		**Pre-test (n=235)**	**60%**	**0.18**
		Post-test (n=293)	**67%**	
	**Q10** Ground acts on the front wheel	**Pre-test (n=214)**	**66%**	**0.26**
		Post-test (n=293)	**75%**	
	Q11 Ground acts on the rear wheel	**Pre-test (n=214)**	**34%**	**0.65**
		Post-test(n=293)	**77%**	
	**Q12** Ground acts on the front wheel	**Pre-test (n=217)**	**34%**	**0.58**
		Post-test (n=293)	**72%**	
	Q13 Ground acts on the rear wheel	**Pre-test (n=211)**	**70%**	**0.20**
		Post-test (n=293)	**76%**	

For Q1, Q2 and Q3, when we consider the percentage of students with correct answer, we found that most students got high scores in both the pre- and post-tests (more than 85 percent). These three questions involve the concept of frictional force in the horizontal direction. In contrast, with the same concept but different context of Q6, the result revealed that the students' percentage with correct answer increased from 22% to 54%. This indicates that the students have difficulty to determine the direction of the frictional force in this context. Most students with incorrect answers (shown in the Table 5.2), believed that the direction of the frictional force from the ground acting on the foot of the soccer player points to the left hand side while the soccer player is running and no skidding to a ball from left to right hand side. This refers to the alternative concept that the frictional force is always opposite to the direction of the object motion. Moreover, it is possible that some students with correct answer in the contexts of Q2 and Q3 held this alternative concept. We also found that in general Thai textbooks (e.g. the IPST textbook) and education websites usually show the horizontal context of frictional forces such as pushing a book placed on a Table. Students may be familiar to this context and can correct the Q2 and Q3. Although, context in Q6 involves the everyday life situation, students might have never noticed, and have less chance to meet in the classes and Thai textbooks. Therefore, to correct the students' alternative concepts the instructor should offer several contexts of learning in each concept. The discussion in various complex situations for a concept is necessary for enhancing students understanding (Mohammad et al., 2008).

For Q4 and Q5, the students' responses were shown in the Table 5.3 in the previous chapter. Again Thai students are not familiar to both contexts in their classes. There are 55% and 39% of students with correct answer in the post-test in Q4 and Q5 respectively. After learning, for Q4 most students still believed that there is no frictional force between the thumb and the glass because the glass is stationary. For Q5 most believed that while the glass is lifting up with a constant velocity, the direction of the frictional force by which the thumb acts on the glass point to downward direction. Both questions reveal the alternative concept that the frictional force opposes the object movement; no motion, no frictional force. In this research we tried to help students to understand this concept by using the bristle demonstration and the discussion of the free-body diagram, added up with other vertical situations. In frictional force classrooms, teachers should more emphasize on the vertical directions of frictional force (Ugo et al., 2007).

Q7 and Q8 involve the inclined directions of frictional forces. We found that the percentage of students with correct answer in post-test in Q7 (75%) is less than that in Q8 (99%), and similar to the pre-test. Both contexts in Q7 and Q8 are a few different but significant. The object is sliding down on the slippery inclined plane for Q7, and on the rough inclined plane for Q8. The interview results showed some students believed that the frictional force always exists while the object is moving. So these students believed the answers of both questions were the same.

For the situation of the object rotation, the results of Q9-Q13 were shown in the Table 5.5. We found that for all situations most students believed the direction of frictional force, by which the ground acts on the wheel, is opposite with the wheel movement. It refers to the alternative concept that the frictional force is always opposite to the motion of the object. By using this misconception, students got score from Q9, Q10 and Q13 as shown by the high percentage of students with correct answer in pre-test. With the same misconception, they did not get score form Q11 and

Q12, as shown by almost a half of lower of percentage of students with correct answer in pre-test. Students consistently used this alternative concept for many questions in different contexts. If students strongly hold an alternative concept, they tend to use it for solving every related item (Clough & Driver, 1983; Licht & Thifs, 1990; Palmer, 1993; Thongchai et al., 2011).

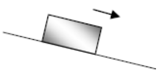
We have designed the frictional force learning module to help students to understand the concepts. The module is based on the constructivist learning theory, which aims to facilitate students to construct the scientifically accepted conceptions by their own. The active learning approach used in this step is the hands-on, which focus on practice by doing and teaching each other. Students do experiments by using the bristle tools constructed by the researchers, take note in the sheet, and discuss with their peers and instructor. When we evaluated the efficiency of this module regarding the directions of frictional force by using the normalized gain via the pre-and post-tests, we found that the average gain was higher than 0.3. It has indicated that students' learning gain was enriched into the middle level after the instruction by using our learning module. In contrast, if students learned with the traditional methods, the learning gain was in the low level (or lower than 0.3) (Hake, 1998; Bao, 2006; Coletta & Phillips, 2005; Marx & Cummings, 2007).

For some items with low gain (Q9, Q10 and Q13) more attentions have to be paid. As aforementioned, it was not clear whether students got score from these questions (in the pre-test) with the correct idea or not. However, around 70% of these students can correctly answer each item in the set of FFCS involving the object rotation (Q9-Q13) in the post-test. The consistency responses vigorously indicate the quality of the module.

6.2 Students' Learning Regarding the Type of the Frictional Force

The frictional learning module for this concept is administered by the learning process of the ILDs approach. The results in Table 6.2 show that this learning module can improve students' learning gain into the middle level. The benefit of ILDs approach has been agreeably reported by many physics education researchers (Thornton & Sokoloff, 1997; Redish et al., 1997; Trumber & Gelbman, 2000).

Table 6.2: The percentage of students with correct answer of pre- and post-tests and students' learning gain regarding the types of the frictional force in various situations

The Items		% Students with Correct Answer	Learning Gain (<g>)
The horizontal situation			
Q1 **Stationary** 	**Pre-test (n=273)**	**85%**	**0.70**
	Post-test (n=293)	**96%**	
Q2 **Stationary** 	**Pre-test (n=273)**	**84%**	**0.87**
	Post-test (n=293)	**98%**	
Q3 **The constant speed** 	**Pre-test (n=293)**	**87%**	**0.93**
	Post-test (n=293)	**99%**	
Q6 	**Pre-test (n=287)**	**53%**	**0.32**
	Post-test (n=293)	**78%**	
The vertical situation			
Q4 	**Pre-test (n=293)**	**50%**	**0.27**
	Post-test (n=293)	**65%**	
Q5 **The constant velocity** 	**Pre-test (n=293)**	**18%**	**0.26**
	Post-test (n=293)	**39%**	
The inclined situation			
Q7 	**Pre-test (n=293)**	**59%**	**0.44**
	Post-test (n=293)	**77%**	
Q8 	**Pre-test (n=287)**	**77%**	**0.65**
	Post-test (n=293)	**92%**	

The situations of the object rotation				
Q9 		**Pre-test (n=293)**	**16%**	**0.61**
		Post-test (n=293)	**67%**	
	**Q10** Ground acts on the front wheel	**Pre-test (n=287)**	**14%**	**0.60**
		Post-test (n=293)	**66%**	
	Q11 Ground acts on the rear wheel	**Pre-test (n=287)**	**18%**	**0.61**
		Post-test (n=293)	**68%**	
	**Q12** Ground acts on the front wheel	**Pre-test (n=287)**	**10%**	**0.63**
		Post-test (n=293)	**67%**	
	Q13 Ground acts on the rear wheel	**Pre-test (n=287)**	**16%**	**0.57**
		Post-test (n=293)	**64%**	

However, Q4 and Q5, which relate to the vertical situation, showed the low gain (or lower than 0.3). When we considered the students' responses in Table 5.7 of the previous chapter, we found that some students believed that the frictional force did not exist while the glass is just being held in the air. The interview results show that these students thought that there is no external force acting on the glass, so there is no frictional force. They believed that if there was external force acting on the object, like Q2, the frictional force existed. But in Q4, they totally forgot the weight of the glass. For Q5, most students believed that while the glass is lifting up, the kinetic friction exists. They did not consider the interaction between the thumb and the glass that there is no sliding. To help students absolutely understand the types of frictional force, the situations, similar to Q4 and Q5, should be more discussed in the frictional force topic.

For Q7, some students believed that there is a kinetic friction while the object is sliding down on the slippery inclined plane (as shown in Table 5.8). In fact, there is no frictional force on the slippery ground. It indicated the less understanding on the operational definitions and limiting conditions of the frictional force concept. Similarly, in fact, Q9-Q13 involves the static friction, but most students believed it was the kinetic friction since the wheel was moving. Therefore, to help students understand this concept the instructor should clearly state and emphasize the operational definitions of static and kinetic frictions in the first class (Hake, 2010). Moreover, teachers should offer several everyday life contexts to help students understand that the kinetic friction involves the sliding movement of the object (Efthimiou & Llewellyn, 2007).

6.3 Students' Learning on the Effect Factors to the Magnitude of the Frictional Force

In this study, there are three factors we checked the students' understanding regarding the magnitude of the frictional force; (1) the apparent contact area of the objects, (2) the sliding speed of the object, and (3) the surface roughness of the materials. The frictional learning module for this concept is administered by the ILDs approach. The results in Table 6.3 show that this learning module can improve students' learning gain into the middle level. Most students, who believed that the magnitude of frictional forces depends on the size of contact area, and the sliding speed of the object (as shown in the percentage of the pre-test), have changed their ideas into the scientifically accepted conception that it only depends on the surface roughness of the materials after the instruction by using our module (as shown in the percentage of the post-test). As aforementioned, it is the assumption of the frictional force concepts for high school students.

Table 6.3: The percentage of students with correct answer of pre- and post-tests and students' learning gain regarding the effect factors to the magnitude of the frictional force.

The Items		% Students with Correct Answer	Learning Gain (<g>)
The magnitude of the frictional force doesn't depend on the apparent contact area			
Q14 	**Pre-test (n=293)**	**12%**	**0.68**
	Post-test (n=293)	**74%**	
Q18 	**Pre-test (n=293)**	**12%**	**0.54**
	Post-test (n=293)	**60%**	
The magnitude of the frictional force doesn't depend on the sliding speed of the object			
Q15 	**Pre-test (n=273)**	**12%**	**0.69**
	Post-test (n=293)	**73%**	
Q16 	**Pre-test (n=273)**	**9%**	**0.71**
	Post-test (n=293)	**74%**	
Q17 	**Pre-test (n=293)**	**11%**	**0.62**
	Post-test (n=293)	**66%**	
The magnitude of the frictional force depends on the roughness of both surfaces in contact			
Q19 	**Pre-test(n=293)**	**13%**	**0.66**
	Post-test(n=293)	**70%**	
Q20 	**Pre-test(n=293)**	**44%**	**0.80**
	Post-test(n=293)	**89%**	

6.4 Summary

This frictional force learning module has been constructed following the key processes of the conceptual change strategy, namely the ILDs and hands-on approaches. It can be much more effective than lecture-based teaching method in enhancing conceptual understanding of frictional forces as examined by the normalized gain. The teaching processes in the module were constructed following the alternative concepts of students. It also focused on the learning by doing experiments and working as a group. Instructor and students always discussed to exchange ideas in various everyday life contexts. These are the ways to promote the conceptual change (DiSessa, 1993; Goldberg & Bendall, 1995; Hewson & Hewson, 1983; Posner et al., 1982).

CHAPTER VII
CONCLUSIONS

This chapter presents the summary of this research comprising the answers of the research questions, the limitation of the study, and the recommendation for the future work.

7.1 Summary of this Research

This research was organized to enhance Thai high school students understanding of the frictional force. The researchers have developed the frictional force learning module based on the hands-on and ILDs approaches. The module consisted of 3 main subtopics of the frictional force; (1) directions of frictional forces, (2) types of frictional forces, and (3) the effect factors on the magnitude of frictional forces. In each subtopic, we have provided both the lesson plan and its learning tools such as the demonstration sets and the work sheets. We have created the assessment instrument called the Frictional Force Conceptual Survey (FFCS). The 20 open-ended questions of the current version of the FFCS are composed of the concepts of directions and types of frictional forces (Q1-Q13) as well as effect factors on the frictional force magnitude (Q14-Q20). The FFCS were vigorously evaluated by the Item-Objective Congruence Index (IOC index), the KR-21 reliability test, the Item difficulty index (P index), and the Item discrimination index (D index). We have tested the module with students, and modified it from the students' suggestions and experts' advice. Ultimately, we applied the frictional force learning module with 293 Thai high school students in Mathayomsuksa 4. The outcomes revealed that the students learning gain, from the instruction by using the frictional force learning module constructed by the researchers, was in the medium level. Moreover, the satisfaction questionnaire results exhibited that more than 90% of these students agreed that they have learned the frictional force from our learning module.

7.2 Answering Research Questions

The answers of two research questions in this study are shown here.

Research Question 1: What are the alternative concepts of frictional forces held by Thai high school students?

Answer:

We have explored 241 Thai high school students via the FFCS for finding out their alternative concepts on the frictional force. Moreover, we found the alternative concepts of Thai students when we did other steps in this research. The whole alternative concepts on frictional forces found in this research were shown in Table 7.1. These are categorized by concepts namely (1) directions of frictional forces, (2) types of frictional forces, and (3) effect factors to the frictional force magnitude.

Table 7.1: Thai high school students' alternative concepts of frictional forces

Frictional Force Topics	Students' Alternative Concepts
1. Directions of frictional forces	1. The direction of frictional forces is always opposite to the motion of the object. 2. The direction of frictional forces is always opposite to that of the force exerted on the object. 3. The direction of frictional forces is opposite to that of acceleration.
2. Types of frictional forces	4. When the object moves, the kinetic friction always acts between the contact areas. 5. When the object moves with a constant velocity, the net force is zero, so there is no frictional force as well.
3. Effect factors on the frictional force magnitude	6. The magnitudes of friction forces depend on the apparent contact areas. 7. The magnitudes of friction forces depend on the sliding speed of the object.

Research Question 2: Does the learning module based on the hands-on and the Interactive Lecture Demonstrations (ILDs) approaches designed by the researchers increase high school students' conceptual understanding of frictional forces?

Answer:

Yes, the learning module has increased student conceptual understanding of the frictional force. This was proved by the normalized gain. It indicated that the instruction by using our learning module enhanced students' learning to the middle gain area. Each student's alternative concept of frictional forces found in this research (as shown in the Table 7.1) is corrected by the instructional tools in the learning module as shown in the Table 7.2.

Table 7.2: The instructional tools in our frictional force learning module that use to correct the corresponding alternative concepts

Topics of Students' Alternative Concepts	Instructional Tools in the Frictional Force Learning Module
Directions of frictional forces	*Lesson Plans*: 1, and 2 *Demonstration set*: **A1**, **A2**, **A3**, and **A4** (presented in the Table 4.2 in the chapter IV) *Work sheets:* **W1**, **W1**, **W3**, and **W4** (presented in the Appendix D)
Types of frictional forces	*Lesson Plans*: 3 *Demonstration set*: **B1** and **B2** (presented in the Table 4.3 in the chapter IV) *Work sheets*: **W5** and **W6**
Effect factors on the frictional force magnitude	*Lesson Plans*: 4 *Demonstration set*: **C1** and **C2** (presented in the Table 4.4 in the chapter IV) *Work sheets*: **W7**, **W8**, and **W9**

7.3 Limitations of this Research

Although this research is forcefully conducted and revised to achieve the statistically reliable study, here are some limitations.

(1) We only focus on the concepts but not cover the problem solving of the frictional force.

(2) The whole process of our module may take longer time than we propose. It depends on the background knowledge of learners.

7.4 Recommendations for Further Research

The recommendations for further works are;

(1) the development of the FFCS to be the multiple-choice test,

(2) the development of the bristle tools to be both demonstration sets for directions of frictional force and experimental instruments for calculating the magnitude of frictional forces, and

(3) the development of the demonstration regarding the effect factors on the magnitude of the frictional force to be a lower cost instrument.

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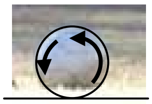
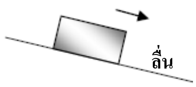
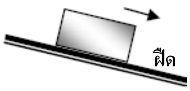
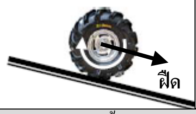
APPENDICES

APPENDIX A
TABLE OF THE INDEX OF ITEM-OBJECTIVE CONGRUENCE (THE IOC INDEX)

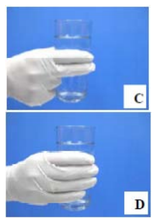
ตารางพิจารณาความสอดคล้องระหว่างข้อสอบกับจุดประสงค์เชิงพฤติกรรม

<u>คำชี้แจง</u> ตารางนี้ออกแบบเพื่อให้ผู้เชี่ยวชาญพิจารณาว่าข้อสอบนั้นๆ วัดได้ตรงตามจุดประสงค์เชิงพฤติกรรมหรือไม่ โดยถ้า ***"แน่ใจว่าตรง"*** ให้ทำเครื่องหมายในช่อง ***" +1 "*** แต่ถ้า ***"แน่ใจว่าไม่ตรง"*** ให้ทำเครื่องหมายในช่อง ***" -1 "*** และถ้า ***"ไม่แน่ใจว่าตรงหรือไม่"*** ให้ทำเครื่องหมายในช่อง ***" 0 "***

<table>
<tr><th rowspan="3">วัตถุประสงค์เชิงพฤติกรรม</th><th colspan="5">คำถาม</th><th colspan="3" rowspan="2">พิจารณา</th></tr>
<tr><th rowspan="2">สถานะการณ์</th><th colspan="3">ชนิดแรงเสียดทาน</th><th rowspan="2">วาดลูกศรลงบนรูปภาพแสดงทิศของแรงเสียดทาน</th></tr>
<tr><th>สถิต</th><th>จลน์</th><th>ไม่มีแรงเสียดทาน</th><th>+1</th><th>0</th><th>-1</th></tr>
<tr><td rowspan="5">นักเรียนสามารถบอกชนิดของแรงเสียดทานและวาดลูกศรแสดงทิศของแรงเสียดทานที่พื้นกระทำต่อวัตถุในสถานการณ์แนวราบได้</td><td colspan="8">จงระบุชนิดและทิศของแรงเสียดทานที่<u>พื้นกระทำต่อกระติกน้ำร้อน</u></td></tr>
<tr><td>1. กระติกน้ำร้อนวางอยู่นิ่งบนพื้นฝืด</td><td></td><td></td><td></td><td>
</td><td></td><td></td><td></td></tr>
<tr><td>2. ออกแรงผลักกระติกน้ำร้อนไปทางซ้าย กระติกน้ำร้อนยังคงอยู่นิ่ง</td><td></td><td></td><td></td><td>
</td><td></td><td></td><td></td></tr>
<tr><td>3. ออกแรงผลักกระติกน้ำร้อนไปทางซ้าย กระติกน้ำร้อนเคลื่อนที่ไปทางซ้าย ด้วย<u>ความเร็วคงตัว</u></td><td></td><td></td><td></td><td>
</td><td></td><td></td><td></td></tr>
<tr><td>4. ออกแรงผลักกระติกน้ำร้อนไปทางซ้าย กระติกน้ำร้อนเคลื่อนที่ไปทางซ้าย โดยมีอัตราเร็วเพิ่มขึ้นอย่างสม่ำเสมอ (<u>ความเร่งคงตัว</u>)</td><td></td><td></td><td></td><td>
</td><td></td><td></td><td></td></tr>
</table>

วัตถุประสงค์เชิงพฤติกรรม	คำถาม					พิจารณา		
	สถานะการณ์	ชนิดแรงเสียดทาน			วาดลูกศรลงบนรูปภาพแสดงทิศของแรงเสียดทาน			
		สถิต	จลน์	ไม่มีแรงเสียดทาน		+1	0	-1
นักเรียนสามารถบอกชนิดของแรงเสียดทานและวาดลูกศรแสดงทิศของแรงเสียดทาน ที่พื้นกระทำต่อวัตถุในสถานการณ์แนวดิ่งได้	จงระบุชนิดและทิศของแรงเสียดทานที่ **มือกระทำต่อแก้ว**							
	5. มือจับแก้วน้ำให้**อยู่นิ่ง**ในอากาศ							
	6. มือจับแก้วน้ำแล้วทำให้แก้วน้ำเคลื่อนที่ขึ้นด้วยความเร็วคงตัว							
	7. มือจับแก้วน้ำแล้วทำให้แก้วน้ำเคลื่อนที่ขึ้นด้วยความเร่งคงตัว							
นักเรียนสามารถบอกชนิดของแรงเสียดทานและวาดลูกศรแสดงทิศของแรงเสียดทานที่พื้นกระทำต่อวัตถุในสถานการณ์แนวราบได้	จงระบุชนิดและทิศของแรงเสียดทาน สำหรับเหตุการณ์ที่นักฟุตบอลกำลังวิ่งเข้าหาลูกฟุตบอลที่กำลังกลิ้งโดยไม่ไถล							
	8.แรงเสียดทานที่**พื้นสนามกระทำต่อเท้าซ้าย**ของนักฟุตบอล							
	9.แรงเสียดทานที่**พื้นสนามกระทำต่อลูกฟุตบอล**(ลูกฟุตบอลกำลังกลิ้งโดยไม่ไถลไปทางซ้าย)							
นักเรียนสามารถบอกชนิดของแรงเสียดทานและวาดลูกศรแสดงทิศของแรงเสียดทานที่พื้นกระทำต่อวัตถุในสถานการณ์แนวพื้นเอียงได้	จงระบุชนิดและทิศของแรงเสียดทานที่**พื้นกระทำต่อวัตถุ**ต่อไปนี้							
	10.ปล่อยกล่องให้ไถลลงพื้นเอียง**ลื่น**							
	11.ปล่อยกล่องให้ไถลลงพื้นเอียง**ฝืด**							
	12.ปล่อยล้อรถให้**กลิ้งแบบไม่ไถล**ลงพื้นเอียง**ฝืด**							
นักเรียนสามารถบอกชนิดของแรงเสียดทานและวาดลูกศรแสดงทิศของแรงเสียดทานที่พื้นกระทำต่อวัตถุในสถานการณ์ที่วัตถุแข็งแกร็งกลิ้งโดยไม่ไถลได้	จงระบุทิศของแรงเสียดทาน**ที่พื้นกระทำต่อล้อรถ**ในแต่ละสถานการณ์ต่อไปนี้							
	13. แรงเสียดทานที่พื้นกระทำต่อล้อรถเข็น ขณะที่รถเข็นกำลังเคลื่อนที่ไปทางซ้าย เมื่อผู้ชายออกแรงเข็นไปทางซ้าย							

วัตถุประสงค์เชิงพฤติกรรม	คำถาม							พิจารณา		
	สถานการณ์		ชนิดแรงเสียดทาน			วาดลูกศรลงบนรูปภาพแสดงทิศของแรงเสียดทาน		+ 1	0	- 1
			สถิต	จลน์	ไม่มีแรงเสียดทาน					
	เด็กน้อยกำลังปั่นจักรยานสามล้อ โดยออกแรงปั่นจักรยานด้วยล้อหน้าไปทางขวามือ ดังรูป 	16.								
		17.								
	นักปั่น กำลังปั่นให้จักรยานเคลื่อนที่ขึ้นเขา 	14.								
		15.								

วัตถุประสงค์เชิงพฤติกรรม	คำถาม		พิจารณา		
	สถานการณ์	ภาพประกอบ	+ 1	0	- 1
นักเรียนสามารถอธิบายได้ว่า แรงเสียดทานขึ้นกับลักษณะของสองผิวสัมผัสที่สัมผัสกัน แต่ไม่ขึ้นกับขนาดพื้นที่สัมผัสของวัตถุ	**จงตอบคำถามในสถานการณ์ต่อไปนี้ พร้อมทั้งบอกเหตุผล**				
	18. นักแข่งคนหนึ่งเสียการควบคุมมอเตอร์ไซค์ทำให้เกิดอุบัติเหตุดังรูป ซึ่งทำให้ร่างของเขาไถลไปบนพื้นถนน โดยนักแข่งคนนี้ใส่ชุดแข่งที่มีผิวเรียบและทำจากวัสดุชนิดเดียวกันตลอดทั้งตัว ถ้าร่างของนักแข่งคนนี้ไถลบนพื้นถนนในลักษณะที่ต่างกันคือ **1)ไถลโดยใช้แผ่นหลังถูไปกับพื้นถนน** และ **2) ไถลโดยใช้สีข้างของลำตัวถูไปกับพื้นถนน** แรงเสียดทานที่เกิดขึ้นระหว่างการไถลของแต่ละลักษณะ **<u>เท่ากันหรือไม่</u>** เพราะเหตุใด **คำตอบ**.................**เพราะว่า**				
	23. ชายคนหนึ่งสวมถุงมือยางผิวเรียบจับแก้วน้ำแล้วยกขึ้นโดยไม่ไถลในแนวดิ่ง ดังรูป **C** ถ้าเขาก็จับแก้วน้ำใบเดียวกันและยกขึ้นในลักษณะเดียวกันดังรูป **D** อยากทราบว่าแรงเสียดทานที่นิ้วมือทั้งหมดกระทำต่อแก้วน้ำ ในรูป **C** และรูป **D** **<u>เท่ากันหรือไม่</u>** เพราะเหตุใด **คำตอบ**……………......................**เพราะว่า** ………………………………………………………………………………				

วัตถุประสงค์เชิงพฤติกรรม	คำถาม		พิจารณา		
	สถานะการณ์	ภาพประกอบ	+ 1	0	- 1
นักเรียนสามารถอธิบายได้ว่าแรงเสียดทานขึ้นกับลักษณะของสองผิวสัมผัสที่สัมผัสกัน แต่ไม่ความเร็วของวัตถุ	**19.** ช้างเชือกหนึ่งกำลังลากท่อนซุงบนพื้นดินแข็งเรียบ เริ่มแรกช้างลากท่อนซุงโดยการก้าวเดินธรรมดา ต่อมาควาญช้างออกคำสั่งให้ช้างวิ่ง อยากทราบว่าแรงเสียดทานที่พื้นดินกระทำต่อผิวด้านล่างของท่อนซุง ขณะที่ช้างเดินและวิ่ง **เท่ากันหรือไม่** เพราะเหตุใด **คำตอบ**……………....................**เพราะว่า** ……………………………………………………………………				
นักเรียนสามารถอธิบายได้ว่าแรงเสียดทานขึ้นกับลักษณะของสองผิวสัมผัสที่สัมผัสกัน แต่ไม่ความเร็วของวัตถุ	**21.** คนงานออกแรงดันตู้เหล็กที่วางอยู่บนพื้นห้อง เคลื่อนที่ด้วยความเร็วค่าหนึ่ง ต่อมาเขาดันตู้เหล็กให้เคลื่อนที่ด้วยความเร็วเพิ่มเป็นสองเท่าของช่วงแรก อยากทราบว่าแรงเสียดทานที่พื้นห้องกระทำต่อตู้เหล็กทั้งสองช่วง **เท่ากันหรือไม่** เพราะเหตุใด **คำตอบ**……………....................**เพราะว่า** ……………………………………………………………………				
	22. เด็กคนหนึ่งกำลังเล่นกระดานลื่น ขณะที่ไถลผ่านตำแหน่ง (A) และตำแหน่ง (B) ตามลำดับ โดยความเร็วในการไถลที่ตำแหน่ง (A) น้อยกว่า ความเร็วในการไถลที่ตำแหน่ง (B) อยากทราบว่าแรงเสียดทานที่พื้นกระดานลื่นกระทำต่อก้นเด็ก ที่ตำแหน่ง (A) และตำแหน่ง (B) **เท่ากันหรือไม่** เพราะเหตุใด **คำตอบ**……………....................**เพราะว่า** ……………………………………………………………………				
นักเรียนสามารถอธิบายได้ว่าแรงเสียดทานขึ้นกับลักษณะของสองผิวสัมผัสที่สัมผัสกันของวัตถุ	**24.** ตู้เสื้อผ้าใบหนึ่งวางอยู่บนพื้นคอนกรีต มีผู้หญิงผอมบางออกแรงผลักตู้เสื้อผ้าให้ไถลด้วยความเร็วคงที่บนพื้นคอนกรีต ทันใดนั้นมีชายร่างกำยำคนหนึ่งมาผลักตู้เสื้อผ้าใบเดียวกันให้ไถลด้วยความเร็วเดียวกับผู้หญิงผอมบางผลัก แรงเสียดทานที่พื้นกระทำต่อตู้เสื้อผ้าของทั้งสองคน **เท่ากันหรือไม่** เพราะเหตุ **คำตอบ**……………....................**เพราะว่า** ……………………………………………………………………				
	25. แผ่นอะคริลิก และแผ่นแก้ว ซึ่งมีขนาดและมวลเท่ากัน ถูกดึงให้เคลื่อนที่ไปด้วยความเร็วคงที่บนพื้นโต๊ะราบดังรูป อยากทราบว่าแรงเสียดทานที่ พื้นโต๊ะกระทำต่อแผ่นอะคริลิค กับพื้นโต๊ะกระทำต่อแผ่นแก้ว **เท่ากันหรือไม่** เพราะเหตุใด **คำตอบ**……………...**เพราะว่า** ……………………………………………………………………				

ความคิดเห็นเพิ่มเติม

………

………

………

………

ลงชื่อ... ผู้เชี่ยวชาญ

(..)

ตำแหน่ง..

APPENDIX B
FRICTIONAL FORCE CONCEPTUAL SURVEY
(THE LAST VERSION)

ข้อสอบวัดความเข้าใจ เรื่องแรงเสียดทาน

กำหนดให้ : เวลาในการทำข้อสอบ 30 นาที

ทุกคำถามในแบบทดสอบนี้ไม่คิดแรงต้านอากาศ

แบบสำรวจนี้เป็นส่วนหนึ่งของงานวิจัย ข้อมูลที่ได้จากแบบสำรวจจะถูกนำไปใช้เป็นส่วนหนึ่งในการวิจัย **โดยข้อมูลส่วนตัวของท่านจะไม่ถูกนำไปเปิดเผยหรือเผยแพร่**

ข้าพเจ้า ☐ ยินยอม ☐ ไม่ยินยอม ให้นำข้อมูลในแบบสำรวจนี้ไปใช้ในการวิจัย

ลงชื่อ..

(..)

แบบทดสอบความเข้าใจ เรื่องแรงเสียดทาน

<u>คำชี้แจง</u> ให้นักเรียนทำเครื่องหมาย ✓ ระบุชนิดของแรงเสียดทาน (ถ้ามี) และ**วาดลูกศรลงบนรูปภาพ**เพื่อแสดงทิศของแรงเสียดทาน ในแต่ละสถานการณ์

<u>ตอนที่ 1</u> จงระบุชนิดและทิศของแรงเสียดทานที่**<u>พื้นกระทำต่อกระติกน้ำร้อน</u>**

สถานการณ์	**แรงเสียดทาน**			**วาดลูกศรลงบนรูปภาพแสดงทิศของแรงเสียดทาน**
	สถิต	**จลน์**	**ไม่มีแรงเสียดทาน**	
1. กระติกน้ำร้อนวางอยู่นิ่งบนพื้นฝืด				
2. ออกแรงผลักกระติกน้ำร้อนไปทางซ้าย กระติกน้ำร้อนยังคงอยู่นิ่ง				
3. ออกแรงผลักกระติกน้ำร้อนไปทางซ้าย กระติกน้ำร้อนเคลื่อนที่ไปทางซ้าย โดยมีอัตราเร็วเพิ่มขึ้นอย่างสม่ำเสมอ (**<u>ความเร่งคงตัว</u>**)				

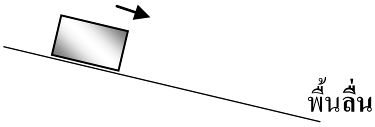
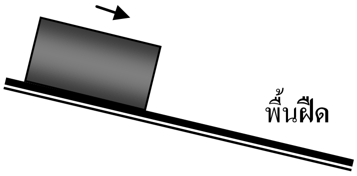
<u>ตอนที่ 2</u> จงระบุชนิดและทิศของแรงเสียดทานที่ **<u>มือกระทำต่อแก้ว</u>**

สถานการณ์	**แรงเสียดทาน**			**วาดลูกศรลงบนรูปภาพแสดงทิศของแรงเสียดทาน**
	สถิต	**จลน์**	**ไม่มีแรงเสียดทาน**	
4. มือจับแก้วน้ำให้**<u>อยู่นิ่ง</u>**ในอากาศ				
5. มือจับแก้วน้ำแล้วทำให้แก้วน้ำเคลื่อนที่ขึ้นด้วยความเร็วคงตัว				

<u>ตอนที่ 3</u> จงระบุชนิดและทิศของแรงเสียดทาน สำหรับเหตุการณ์ที่นักฟุตบอลกำลังวิ่งเข้าหาลูกฟุตบอลที่กำลังกลิ้งโดยไม่ไถ

สถานการณ์	**แรงเสียดทาน**			**วาดลูกศรลงบนรูปภาพแสดงทิศของแรงเสียดทาน**
	สถิต	**จลน์**	**ไม่มีแรงเสียดทาน**	
6.แรงเสียดทานที่พื้นสนามกระทำต่อเท้าซ้ายของนักฟุตบอล 				

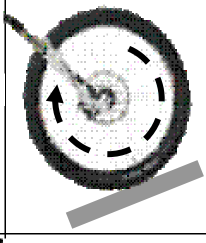
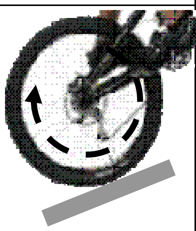
<u>ตอนที่ 4</u> จงระบุชนิดและทิศของแรงเสียดทานที่**<u>พื้นกระทำต่อวัตถุ</u>**ต่อไปนี้

สถานการณ์	**แรงเสียดทาน**			**วาดลูกศรลงบนรูปภาพแสดงทิศของแรงเสียดทาน**
	สถิต	**จลน์**	**ไม่มีแรงเสียดทาน**	
7.ปล่อยกล่องให้ไถลลงพื้นเอียง**<u>ลื่น</u>**				
8.ปล่อยแท่งไม้ให้**<u>กลิ้งแบบไม่ไถล</u>**ลงพื้นเอียง**<u>ฝืด</u>**				

<u>ตอนที่ 5</u> จงระบุทิศของแรงเสียดทานในแต่ละสถานการณ์ต่อไปนี้

สถานการณ์	**แรงเสียดทาน**			**วาดลูกศรลงบนรูปภาพแสดงทิศของแรงเสียดทาน**
	สถิต	**จลน์**	**ไม่มีแรงเสียดทาน**	
9. แรงเสียดทานที่พื้นกระทำต่อล้อรถเข็น ขณะที่รถเข็นกำลังเคลื่อนที่ไปทางซ้าย เมื่อผู้ชายออกแรงเข็นไปทางซ้าย				

ตอนที่ 6 จงระบุชนิดและทิศของแรงเสียดทาน ที่**พื้นกระทำต่อล้อหน้าและล้อหลัง** ของจักรยาน

สถานการณ์		แรงเสียดทาน			วาดลูกศรลงบนรูปภาพแสดงทิศของแรเสียดทาน	
		สถิต	จลน์	ไม่มีแรงเสียดทาน	พื้น*กระทำต่อ*ล้อหลัง	พื้น*กระทำต่อ*ล้อหน้า
นักปั่น กำลังปั่นให้**จักรยานเคลื่อนที่ขึ้นเขา**	**10.**					
จักรยานเคลื่อนที่ขึ้น 	**11.**					
เด็กน้อยกำลังปั่นจักรยานสามล้อ โดยออกแรงปั่นจักรยานด้วยล้อหน้าไปทางขวามือดังรูป	**12.**					
	**13.**					

ตอนที่ 7 จงตอบคำถามในสถานการณ์ต่อไปนี้

14. นักแข่งคนหนึ่งเสียการควบคุมมอเตอร์ไซด์ทำให้เกิดอุบัติเหตุดังรูป ซึ่งทำให้ร่างของเขาไถลไปบนพื้นถนน โดยนักแข่งคนนี้ใส่ชุดแข่งที่มีผิวเรียบและทำจากวัสดุชนิดเดียวกันตลอดทั้งตัว ถ้าร่างของนักแข่งคนนี้ไถลบนพื้นถนนในลักษณะที่ต่างกันคือ **1)ไถลโดยใช้แผ่นหลังถูไปกับพื้นถนน** และ **2)ไถลโดยใช้สีข้างของลำตัวถูไปกับพื้นถนน** แรงเสียดทานที่เกิดขึ้นระหว่างการไถลของแต่ละลักษณะ **เท่ากันหรือไม่** เพราะเหตุใด

คำตอบ..................**เหตุผล**.. ....

15. ช้างเชือกหนึ่งกำลังลากท่อนซุงบนพื้นดินแข็งเรียบ เริ่มแรกช้างลากท่อนซุงโดยการก้าวเดินธรรมดา ต่อมาควาญช้างออกคำสั่งให้ช้างวิ่ง อยากทราบว่าแรงเสียดทานที่พื้นดินกระทำต่อผิวด้านล่างของท่อนซุง ขณะที่ช้างเดินและวิ่ง **เท่ากันหรือไม่** เพราะเหตุใด

คำตอบ……………......................**เพราะว่า** ……………………………………………………………………

………

16. คนงานออกแรงดันตู้เหล็กที่วางอยู่บนพื้นห้อง เคลื่อนที่ด้วยความเร็วคงที่ค่าหนึ่ง ต่อมาเขาดันตู้เหล็กให้เคลื่อนที่ด้วยความเร็วเพิ่มเป็นสองเท่าของช่วงแรก อยากทราบว่าแรงเสียดทานที่พื้นห้องกระทำต่อตู้เหล็กทั้งสองช่วง **<u>เท่ากันหรือไม่</u>** เพราะเหตุใด

คำตอบ…………….......................**เพราะว่า**………………………………………………………………………

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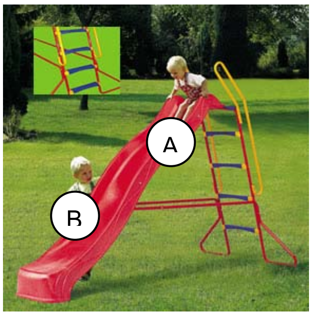

17. เด็กคนหนึ่งกำลังเล่นกระดานลื่น ขณะที่ไถลผ่านตำแหน่ง (A) และตำแหน่ง (B) ตามลำดับ โดยความเร็วในการไถลที่ตำแหน่ง (A) น้อยกว่า ความเร็วในการไถลที่ตำแหน่ง (B) อยากทราบว่าแรงเสียดทานที่พื้นกระดานลื่นกระทำต่อก้นเด็ก ที่ตำแหน่ง (A) และตำแหน่ง (B) **<u>เท่ากันหรือไม่</u>** เพราะเหตุใด

คำตอบ…………….......................**เพราะว่า** ………………………………………………………………………

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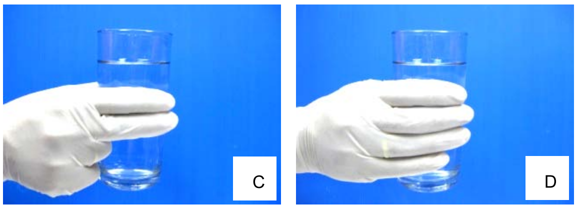

18. ชายคนหนึ่งสวมถุงมือยางผิวเรียบจับแก้วน้ำแล้วยกขึ้นโดยไม่ไถลในแนวดิ่ง ดังรูป **C** ถ้าเขาก็จับแก้วน้ำใบเดียวกันและยกขึ้นในลักษณะเดียวกันดังรูป **D** อยากทราบว่าแรงเสียดทานที่นิ้วมือทั้งหมดกระทำต่อแก้วน้ำ ในรูป **C** และรูป **D** **<u>เท่ากันหรือไม่</u>** เพราะเหตุใด

คำตอบ…………….......................**เพราะว่า** ……………………………………………………………………

……

19. ตู้เสื้อผ้าใบหนึ่งวางอยู่บนพื้นคอนกรีต มีผู้หญิงผอมบางออกแรงผลักตู้เสื้อผ้าให้ไถลด้วยความเร็วคงที่บนพื้นคอนกรีต ทันใดนั้นมีชายร่างกำยำคนหนึ่งมาผลักตู้เสื้อผ้าใบเดียวกันให้ไถลด้วยความเร็วเดียวกับผู้หญิงผอมบางผลัก แรงเสียดทานที่พื้นกระทำต่อตู้เสื้อผ้าของทั้งสองคน **<u>เท่ากันหรือไม่</u>** เพราะเหตุ

คำตอบ…………….......................**เพราะว่า** ……………………………………………………………………

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20. แผ่นอะคริลิก และแผ่นแก้ว ซึ่งมีขนาดและมวลเท่ากัน ถูกดึงให้เคลื่อนที่ไปด้วยความเร็วคงที่บนพื้นโต๊ะราบดังรูป อยากทราบว่าแรงเสียดทานที่ พื้นโต๊ะกระทำต่อแผ่นอะคริลิค กับพื้นโต๊ะกระทำต่อแผ่นแก้ว **<u>เท่ากันหรือไม่</u>** เพราะเหตุใด

คำตอบ……………...

เพราะว่า……………………………………………...

APPENDIX C
LESSON PLANS OF THE FRICTIONAL FORCE CONCEPT

แผนการสอนที่1: เรื่องตำแหน่งและทิศของแรงเสียดทาน
เวลาที่ใช้สอน: 50 นาที

ผลการเรียนรู้ที่คาดหวัง

นักเรียนสามารถเขียนลูกศรแสดงตำแหน่งและทิศทางของแรงเสียดทานในแนวราบได้

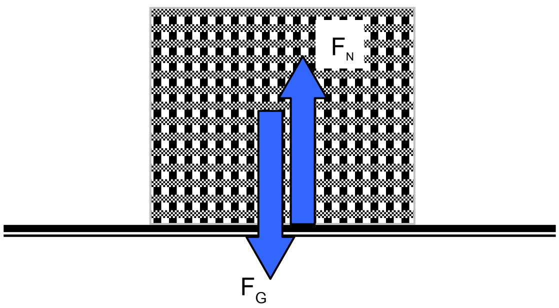
แนวความคิดหลัก

แรงเสียดทาน (Frictional Force; F_f)

"เป็นแรงที่ต้านการเคลื่อนที่เชิงสัมพัทธ์ ระหว่างพื้นผิวสัมผัส"

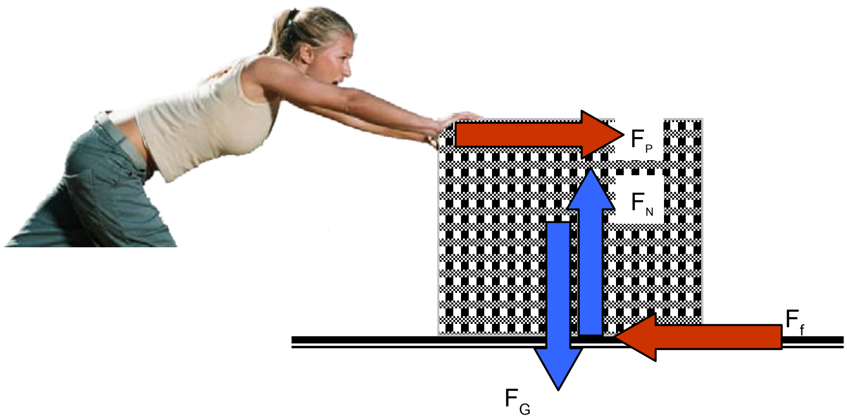
พิจารณาแผนภาพแสดงแรง(Free-Body Diagrams: FBDs)ทั้งหมดที่กระทำต่อวัตถุจากสถานการณ์ต่อไปนี้

- กล่องไม้วางนิ่งอยู่บนพื้นราบ FBDs ของแรงที่กระทำต่อกล่องไม้แสดงได้ดังรูปที่1



รูปที่ 1 แสดงกล่องไม้วางนิ่งบนพื้นราบ

- ออกแรงผลักกล่องไม้ที่วางอยู่บนพื้นราบ FBDs ของแรงที่กระทำต่อกล่องไม้แสดงได้ดังรูปที่2



รูปที่ 2 แสดงผู้หญิงผลักกล่องไม้วางนิ่งบนพื้นราบ

กระบวนการจัดการเรียนรู้

ขั้นนำ(17 นาที)

1. แบ่งนักเรียนออกเป็นกลุ่ม กลุ่มหนึ่งประมาณ 6-7 คน
2. ให้นักเรียนดูคลิปVDO 2-3 คลิป ในเนื้อหาที่เกี่ยวกับแรงเสียดทาน
3. นักเรียนเชื่อมความสัมพันธ์ถึงสถานการณ์ในคลิป VDO กับ เนื้อหาฟิสิกส์
4. ครูนำนักเรียน ทบทวนเนื้อหาฟิสิกส์ ในหัวข้อการเขียนFree-Body Diagrams(FBDs) โดยการสมมติสถานการณ์ที่เกี่ยวกับชีวิตประจำวันของเด็ก เช่น ขอตัวแทนหนึ่งคน มานั่งบนเก้าอี้หน้าห้องเรียน แล้วให้แต่ละกลุ่มเขียน Free-Body Diagrams ของแรงทั้งหมดที่กระทำต่อตัวเพื่อน

ขั้นการเรียนการสอนด้วยกระบวนการ ILD : กิจกรรมที่ 1 (30 นาที)

1. อธิบายชุดอุปกรณ์ ของ **กิจกรรมที่ 1**
2. ให้นักเรียนแต่ละคนทำนายว่าขนแปรงจะมีการเปลี่ยนแปลงหรือไม่ และถ้ามีการเปลี่ยนแปลง ปลายขนแปลงมีทิศชี้ไปทางใด โดยการเขียนลงในใบทำนาย **<u>กรณีที่1</u>** ของตัวเอง
3. ครูกระตุ้นให้นักเรียนแลกเปลี่ยนความเห็นเกี่ยวกับการทำนายของตัวเอง ภายในกลุ่มย่อย
4. นักเรียนเขียนการทำนายใหม่อีกครั้ง(สำหรับคนที่ต้องการเปลี่ยนการทำนายของตัวเอง)
5. ครูเลือกตัวอย่างการทำนายของนักเรียนบางคน แสดงให้เพื่อนๆ ในห้องดู
6. ครูให้นักเรียนแต่ละกลุ่มสาธิต **กิจกรรมที่1**: **<u>กรณีที่1</u>**
7. ครูและนักเรียนแลกเปลี่ยนความคิดเห็น เกี่ยวกับผลที่เกิดขึ้นหลังจากการสาธิต

8. ครูยกตัวอย่างและให้นักเรียนแลกเปลี่ยนความคิดเห็นในสถานการณ์อื่นที่มีหลักการเดียวกัน
9. ดำเนินการตามกระบวนการที่ 2 – 8 กับ **กรณีที่2** และ **กรณีที่3**

ขั้นสรุป(3นาที)

ครูนำสรุปเกี่ยวกับกิจกรรมที่หนึ่ง

เอกสารอ้าง

1. หนังสือเรียน ฟิสิกส์เล่ม1 ชั้นมัธยมศึกษาปีที่4 หลักสูตรการศึกษาขั้นพื้นฐาน พ.ศ. 2544 สถาบันส่งเสริมการสอนวิทยาศาสตร์และเทคโนโลยี

2. http://en.wikipedia.org/wiki/Free_body_diagram

แผนการสอนที่2: **เรื่องทิศของแรงเสียดทาน (ต่อ)**

เวลาที่ใช้สอน: **50 นาที**

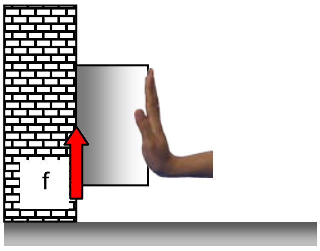
ผลการเรียนรู้ที่คาดหวัง

1. นักเรียนสามารถระบุตำแหน่ง และทิศของแรงเสียดทาน ของวัตถุที่วางตัวในแนวดิ่งได้
2. นักเรียนสามารถระบุตำแหน่ง และทิศของแรงเสียดทาน ของวัตถุที่วางบนพื้นเอียงได้
3. นักเรียนสามารถระบุตำแหน่ง และทิศของแรงเสียดทาน ของวัตถุที่กลิ้งได้

แนวความคิดหลัก

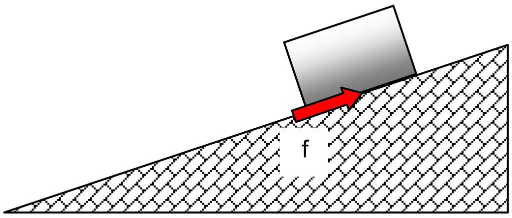
แรงเสียดทานเกิดขึ้นที่รอยต่อของผิวสัมผัสขณะที่ผิวสัมผัสหนึ่งพยายามจะเคลื่อนที่ ผ่านอีกผิวสัมผัสหนึ่ง

ทิศทางของแรงเสียดทานในแนวดิ่ง



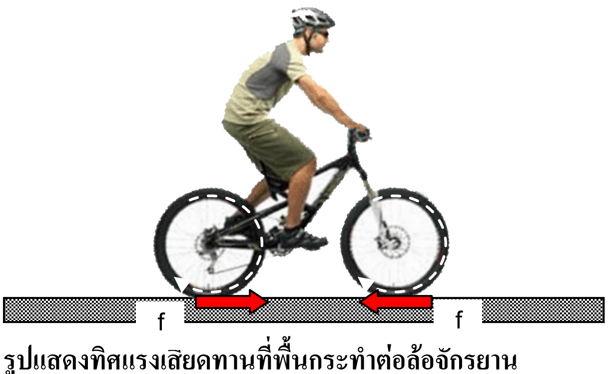
รูปแสดงทิศแรงเสียดทานที่ผนังตึกกระทำต่อกล่อง

ทิศทางของแรงเสียดทานในแนวเอียง



รูปแสดงทิศแรงเสียดทานที่พื้นเอียงกระทำต่อกล่อง

ทิศทางของแรงเสียดทานของวัตถุกำลังกลิ้ง



รูปแสดงทิศแรงเสียดทานที่พื้นกระทำต่อล้อจักรยาน

กระบวกการจัดการเรียนรู้

ขั้นนำ (7นาที)

5. แบ่งนักเรียนออกเป็นกลุ่ม กลุ่มหนึ่งประมาณ 6-7 คน
6. ให้นักเรียนดูคลิปVDO 2-3 คลิป ในเนื้อหาที่เกี่ยวกับแรงเสียดทาน
7. นักเรียนเชื่อมความสัมพันธ์ถึงสถานการณ์ในคลิป VDO กับ เนื้อหาฟิสิกส์
8. ครูยกตัวอย่างในVDO ที่เกี่ยวกับเนื้อหา แล้วให้นักเรียนเขียนFBDs

ขั้นการเรียนการสอนด้วยกระบวนการ ILD : กิจกรรมที่ 1 (40 นาที)

10. อธิบายชุดอุปกรณ์ ของ **กิจกรรมที่ 2**
11. ให้นักเรียนแต่ละคนทำนายว่าขนแปรงจะมีการเปลี่ยนแปลงหรือไม่ และถ้ามีการเปลี่ยนแปลง ปลายขนแปลงมีทิศชี้ไปทางใด โดยการเขียนลงในใบทำนายของตัวเอง
12. ครูกระตุ้นให้นักเรียนแลกเปลี่ยนความเห็นเกี่ยวกับการทำนายของตัวเอง ภายในกลุ่มย่อย
13. นักเรียนเขียนการทำนายใหม่อีกครั้ง(สำหรับคนที่ต้องการเปลี่ยนการทำนายของตัวเอง)
14. ครูเลือกตัวอย่างการทำนายของนักเรียนบางคน แสดงให้เพื่อนๆ ในห้องดู
15. ครูให้นักเรียนแต่ละกลุ่มสาธิต **กิจกรรมที่2**
16. ครูและนักเรียนแลกเปลี่ยนความคิดเห็น เกี่ยวกับผลที่เกิดขึ้นหลังจากการสาธิต
17. ครูยกตัวอย่างและให้นักเรียนแลกเปลี่ยนความคิดเห็นในสถานการณ์อื่นที่มีหลักการเดียวกัน
18. ดำเนินการตามกระบวนที่ 1 – กระบวนการที่ 8 โดยใช้ ***กิจกรรมที่ 3***
19. ดำเนินการตามกระบวนที่ 1 – กระบวนการที่ 8 โดยใช้ ***กิจกรรมที่ 4*** **<u>กรณีที่1</u>**
20. ดำเนินการตามกระบวนที่ 1 – กระบวนการที่ 8 โดยใช้ ***กิจกรรมที่ 4*** **<u>กรณีที่2</u>**
21. ดำเนินการตามกระบวนที่ 1 – กระบวนการที่ 8 โดยใช้ ***กิจกรรมที่ 4*** **<u>กรณีที่3</u>**

ขั้นสรุป (3นาที)

ครูและนักเรียนร่วมกันสรุปทิศทางของแรงเสียดทานในสถานการณ์ต่างๆ

เอกสารอ้าง

1. หนังสือเรียน ฟิสิกส์เล่ม1 ชั้นมัธยมศึกษาปีที่4 หลักสูตรการศึกษาขั้นพื้นฐาน พ.ศ. 2544 สถาบันส่งเสริมการสอนวิทยาศาสตร์และเทคโนโลยี

2. http://en.wikipedia.org/wiki/Free_body_diagra

แผนการสอนที่3: เรื่องชนิดของแรงเสียดทาน
เวลาที่ใช้สอน: 50 นาที

ผลการเรียนรู้ที่คาดหวัง

1. นักเรียนสามารถอธิบายแรงเสียดทานสถิต แรงเสียดทานสถิตสูงสุด และแรงเสียดทานจลน์ได้
2. นักเรียนสามารถจำแนกชนิดของแรงเสียดทานในสถานการณ์ต่างๆได้

แนวความคิดหลัก

ชนิดของแรงเสียดทานคือ แรงเสียดทานระหว่างผิวสัมผัส 2 ผิวที่สัมผัสกันโดยไม่มีการหล่อลื่นและมีการเลื่อนหรือแนวโน้มการเลื่อนระหว่าง2 ผิวสัมผัสนี้

- เกิดขึ้นทั้งในขณะที่เคลื่อนที่และขณะก่อนการเคลื่อนที่ซึ่งมีแนวโน้มที่จะเคลื่อนที่
- ทิศทางอยู่ในแนวสัมผัสระหว่าง2 ผิวสัมผัส

ชนิดของแรงเสียดทานแบ่งออกเป็น 2 ประเภท คือ

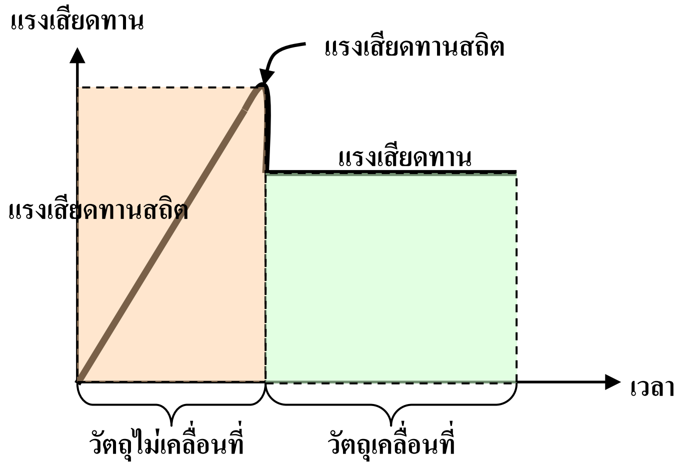
แรงเสียดทานสถิต (Static Friction)

แรงเสียดทานในขณะที่วัตถุมีแนวโน้มการเคลื่อนที่แต่ยังไม่เกิดการเคลื่อนที่ และขนาดของแรงเสียดทานไม่คงที่ขึ้นอยู่กับความมากน้อยของแรงที่พยายามทำให้เคลื่อนที่(แรงที่ทำให้เกิดแนวโน้มการเคลื่อนที่) มีขนาดสูงสุดเท่ากับ $F_{\max} = \mu_s N$

แรงเสียดทานจลน์ (Kinetic Friction)

แรงเสียดทานในขณะที่วัตถุกำลังเคลื่อนที่และมีขนาดคงที่(ในช่วงที่พิจารณาส่วนใหญ่) คือ

$F_k = \mu_k N$



กราฟแสดงความสัมพันธ์ระหว่างแรงเสียดทานกับเวลา

กระบวกการจัดการเรียนรู้

ขั้นนำ (7นาที)

9. แบ่งนักเรียนออกเป็นกลุ่ม กลุ่มหนึ่งประมาณ 6-7 คน
10. ให้นักเรียนดูคลิปVDO 2-3 คลิป ในเนื้อหาที่เกี่ยวกับแรงเสียดทาน
11. นักเรียนเชื่อมความสัมพันธ์ถึงสถานการณ์ในคลิป VDO กับ เนื้อหาฟิสิกส์

ขั้นการเรียนการสอนด้วยกระบวนการ ILD : กิจกรรมที่ 1 (40 นาที)

22. อธิบายชุดอุปกรณ์ ของ **กิจกรรมที่ 5**
23. ให้นักเรียนแต่ละคนทำนายกราฟตำแหน่งและกราฟแรงเสียดทานที่ผิวแผ่นอะคลีลิกกระทำต่อผิวแท่งไม้ เมื่อค่อยๆเพิ่มแรงดึงแท่งไม้ ไปทางขวา จนแท่งไม้เคลื่อนที่โดยการเขียนลงในใบทำนายของตัวเอง
24. ครูกระตุ้นให้นักเรียนแลกเปลี่ยนความเห็นเกี่ยวกับการทำนายของตัวเอง ภายในกลุ่มย่อย
25. นักเรียนเขียนการทำนายใหม่อีกครั้ง(สำหรับคนที่ต้องการเปลี่ยนการทำนายของตัวเอง)
26. ครูเลือกตัวอย่างการทำนายของนักเรียนบางคน แสดงให้เพื่อนๆ ในห้องดู
27. ครูสาธิต**กิจกรรมที่5**
28. ครูและนักเรียนแลกเปลี่ยนความคิดเห็น เกี่ยวกับผลที่เกิดขึ้นหลังจากการสาธิต
29. ครูยกตัวอย่างและให้นักเรียนแลกเปลี่ยนความคิดเห็นในสถานการณ์อื่นที่มีหลักการเดียวกัน
30. อธิบายชุดอุปกรณ์ ของ **กิจกรรมที่ 6**
31. ให้นักเรียนแต่ละคนทำนายลักณะการเคลื่อนที่ของลูกทุเรียนในแบบที่1 และแบบที่2 ลงในใบทำนายของตัวเอง
32. ทำตามกระบวนการที่3 – กระบวนการที่8

ขั้นสรุป (3นาที)

ครูและนักเรียนร่วมกันสรุปชนิดของแรงเสียดทานในแต่ละลักษณะ

เอกสารอ้าง

1. หนังสือเรียน ฟิสิกส์เล่ม1 ชั้นมัธยมศึกษาปีที่4 หลักสูตรการศึกษาขั้นพื้นฐาน พ.ศ. 2544 สถาบันส่งเสริมการสอนวิทยาศาสตร์และเทคโนโลยี

2. http://en.wikipedia.org/wiki/Free_body_diagra

แผนการสอนที่4: เรื่องคุณสมบัติของแรงเสียดทาน
เวลาที่ใช้สอน: 50 นาที

ผลการเรียนรู้ที่คาดหวัง

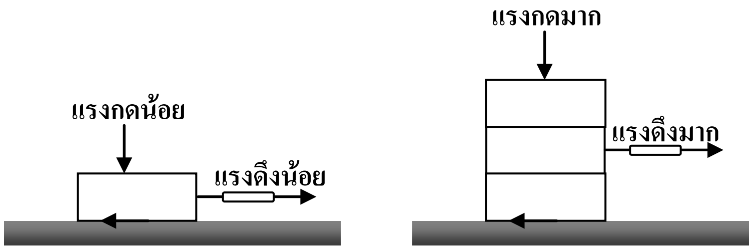
1. นักเรียนสามารถอธิบายได้ว่าแรงเสียดทานไม่ขึ้นกับขนาดพื้นที่สัมผัสของวัตถุ
2. นักเรียนสามารถอธิบายได้ว่าแรงเสียดทานไม่ขึ้นกับความเร็วในการไถลของวัตถุ
3. นักเรียนสามารถอธิบายได้ว่าแรงเสียดทานขึ้นกับชนิดของผิวสัมผัสของวัตถุ

แนวความคิดหลัก

ปัจจัยที่มีผลต่อแรงเสียดทาน

แรงเสียดทานระหว่างผิวสัมผัสจะมีค่ามากหรือน้อยขึ้นอยู่กับ

1. **แรงกดตั้งฉากกับผิวสัมผัส** ถ้าแรงกดตั้งฉากกับผิวสัมผัสมากจะเกิดแรงเสียดทานมาก ถ้าแรงกดตั้งฉากกับผิวสัมผัสน้อยจะเกิดแรงเสียดทานน้อย ดังรูป



(ก) แรงเสียดทานน้อย **(ข) แรงเสียดทานมาก**

รูป ก แรงเสียดทานน้อย รูป ข แรงเสียดทานมาก

2. **ลักษณะของผิวสัมผัส** ถ้าผิวสัมผัสหยาบ ขรุขระจะเกิดแรงเสียดทานมาก ดังรูป ก ส่วนผิวสัมผัสเรียบลื่นจะเกิดแรงเสียดทานน้อยดังรูป

(ค) แรงเสียดทานมาก **(ง) แรงเสียดทานน้อย**

รูป ค แรงเสียดทานมาก รูป ง แรงเสียดทานน้อย

3. **ชนิดของผิวสัมผัส** เช่น คอนกรีตกับเหล็ก เหล็กกับไม้ จะเห็นว่าผิวสัมผัสแต่ละคู่ มีความหยาบขรุขระ หรือเรียบลื่น เป็นมันแตกต่างกัน ทำให้เกิดแรงเสียดทานไม่เท่ากัน

4. **ความเร็วการไถล** วัตถุพื้นผิวแข็ง เมื่อไถลด้วยความเร็วที่ต่างกันคือมากกว่า10 เซนติเมตรต่อวินาที [4] ขนาดของแรงเสียดทานจะมีค่าเท่ากัน

5. **ขนาดพื้นที่สัมผัส** วัตถุชนิดเดียวกันแต่มีขนาดพื้นที่ผิวสัมผัสต่างกัน ขนาดของแรงเสียดทานจะมีค่าเท่ากัน

กระบวกการจัดการเรียนรู้

ขั้นนำ (7นาที)

12. แบ่งนักเรียนออกเป็นกลุ่ม กลุ่มหนึ่งประมาณ 6-7 คน
13. ให้นักเรียนดูคลิปVDO 2-3 คลิป ในเนื้อหาที่เกี่ยวกับแรงเสียดทาน
14. นักเรียนเชื่อมความสัมพันธ์ถึงสถานการณ์ในคลิป VDO กับ เนื้อหาฟิสิกส์

ขั้นการเรียนการสอนด้วยกระบวนการ ILD : กิจกรรมที่ 1 (40 นาที)

33. อธิบายชุดอุปกรณ์ ของ **กิจกรรมที่ 7**
34. ให้นักเรียนแต่ละคนทำนาย โดยการวาดกราฟแรงเสียดทานที่ผิวของอะคลีลิกกระทำต่อผิวด้านA ด้านB และด้านCของแท่งไม้ ลงในใบทำนายของตัวเอง
35. ครูกระตุ้นให้นักเรียนแลกเปลี่ยนความเห็นเกี่ยวกับการทำนายของตัวเอง ภายในกลุ่มย่อย
36. นักเรียนเขียนการทำนายใหม่อีกครั้ง(สำหรับคนที่ต้องการเปลี่ยนการทำนายของตัวเอง)
37. ครูเลือกตัวอย่างการทำนายของนักเรียนบางคน แสดงให้เพื่อนๆ ในห้องดู
38. ครูให้นักเรียนแต่ละกลุ่มสาธิต **กิจกรรมที่7**
39. ครูและนักเรียนแลกเปลี่ยนความคิดเห็น เกี่ยวกับผลที่เกิดขึ้นหลังจากการสาธิต
40. ครูยกตัวอย่างและให้นักเรียนแลกเปลี่ยนความคิดเห็นในสถานการณ์อื่นที่มีหลักการเดียวกัน
41. ทำตามกระบวนที่ 1 – 8 โดยใช้ ***กิจกรรมที่ 8***
42. ทำตามกระบวนที่ 1 – 8 โดยใช้ ***กิจกรรมที่ 9***

ขั้นสรุป (3นาที)

ครูและนักเรียนร่วมกันสรุป

เอกสารอ้างอิง

1. หนังสือเรียน ฟิสิกส์เล่ม1 ชั้นมัธยมศึกษาปีที่4 หลักสูตรการศึกษาขั้นพื้นฐาน พ.ศ. 2544 สถาบันส่งเสริมการสอนวิทยาศาสตร์และเทคโนโลยี
2. http://www.maceducation.com/e-knowledge/2432210100/16.htm
3. http://en.wikipedia.org/wiki/Free_body_diagra
4. Luigi M G and Silvia D (2006) A simple measurement of the sliding friction coefficient Physics Education **41**(3) 232-235

APPENDIX D

WORKSHEETS OF THE FRICTIONAL FORCE LEARNIG

ใบงานที่ 1: ตำแหน่งและทิศของแรงเสียดทานในแนวราบ

วัตถุประสงค์

เพื่อให้นักเรียนใช้ แบบจำลองของขนแปรงระบุทิศทางของแรงเสียดทานในแนวราบได้

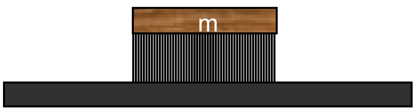
อุปกรณ์

1. ชุดขนแปรง
2. แผ่นยาง
3. กระดาษทำนายผล

ภาพชุดขนแปรงและพื้นยาง

วิธีการและบันทึกผล

<u>กรณีที่1</u> แปรง <u>วางนิ่ง</u> อยู่กับที่ **หยุดนิ่ง**



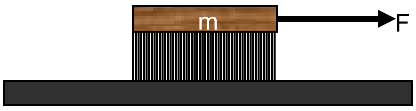
ให้วาดรูปปลายขนแปรงที่เห็น	
<u>ทำนาย</u>	**<u>เฉลย</u>**

มีแรงเสียดทานที่พื้นกระทำต่อปลายขนแปรงหรือไม่ ☐ **มี** ☐ **ไม่มี**

<u>ถ้ามี</u> ให้วาดลูกศรแสดงทิศของแรงเสียดทาน

<u>กรณีที่2</u> ออกแรง (F) ดึงแปรงไปทางขวา แต่แปรง<u>ยังคงอยู่นิ่งอยู่กับที่</u>

หยุดนิ่ง



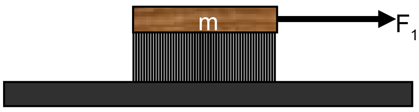
ให้วาดรูปปลายขนแปรงที่เห็น	
<u>ทำนาย</u>	**<u>เฉลย</u>**

มีแรงเสียดทานที่พื้นกระทำต่อปลายขนแปรงหรือไม่ ☐ **มี** ☐ **ไม่มี**

<u>ถ้ามี</u> ให้วาดลูกศรแสดงทิศของแรงเสียดทาน

<u>กรณีที่3</u> จากกรณีที่2 เพิ่มแรงดึงเชือกกระทั่งแปรงเคลื่อนที่ แล้วดึงด้วยแรง **F_1** <u>ให้แปรงเคลื่อนที่ด้วยความเร็ว (v) คงที่</u>

ความเร็ว(v) คงที่



ให้วาดรูปปลายขนแปรงที่เห็น	
ทำนาย	**เฉลย**

มีแรงเสียดทานที่พื้นกระทำต่อปลายขนแปรงหรือไม่ ☐ **มี** ☐ **ไม่มี**

<u>ถ้ามี</u> ให้วาดลูกศรแสดงทิศของแรงเสียดทาน

สรุป

ใบงานที่ 2: ทิศแรงเสียดทานในแนวดิ่ง

วัตถุประสงค์

เพื่อให้นักเรียนใช้ แบบจำลองของขนแปรงระบุทิศทางของแรงเสียดทานในแนวดิ่งได้

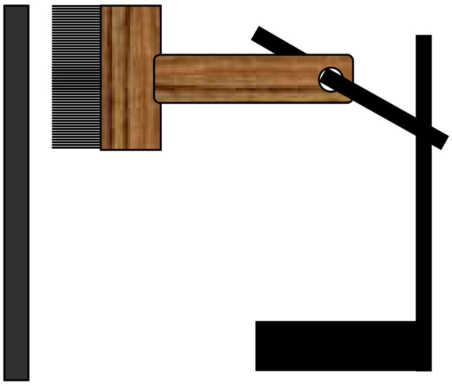
อุปกรณ์

1. แปรงทาสี
2. พื้นยางวางตัวแนวดิ่ง
3. ขาตั้ง
4. ตะเกียบ
5. ตัวล็อก
6. กระดาษทำนายผล

รูปแสดงอุปกรณ์

วิธีการและบันทึกผล

นำ แผ่นยางมาติดไว้ที่ปลายของแปรงทาสี โดยแปรงทาสีหยุดนิ่งดังรูป



ให้วาดรูปปลายขนแปรงที่เห็น	
ทำนาย	เฉลย

มีแรงเสียดทานที่พื้นกระทำต่อปลายขนแปรงหรือไม่ ☐ มี ☐ไม่มี

ถ้ามี ให้วาดลูกศรแสดงทิศของแรงเสียดทาน

สรุป

ใบงานที่ 3: ทิศแรงเสียดทานแนวพื้นเอียง

วัตถุประสงค์

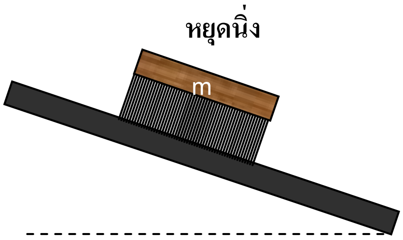
เพื่อให้นักเรียนใช้ แบบจำลองของขนแปรงระบุทิศทางของแรงเสียดทานในแนวพื้นเอียงได้

อุปกรณ์

1. ชุดขนแปรง
2. แผ่นยางวางตัวแนวเอียง
3. กระดาษทำนายผล

ภาพชุดขนแปรงบนพื้นเอียง

วิธีการและบันทึกผล



ให้วาดรูปปลายขนแปรงที่เห็น	
ทำนาย	เฉลย

มีแรงเสียดทานที่พื้นกระทำต่อปลายขนแปรงหรือไม่ ☐ มี ☐ ไม่มี

ถ้ามี ให้วาดลูกศรแสดงทิศของแรงเสียดทาน

สรุป

ใบงานที่ 4: ทิศแรงเสียดทานของล้อจักรยาน

วัตถุประสงค์

เพื่อให้นักเรียนใช้ แบบจำลองของขนแปรงระบุทิศทางของแรงเสียดทานของวัตถุกลิ้งได้

อุปกรณ์

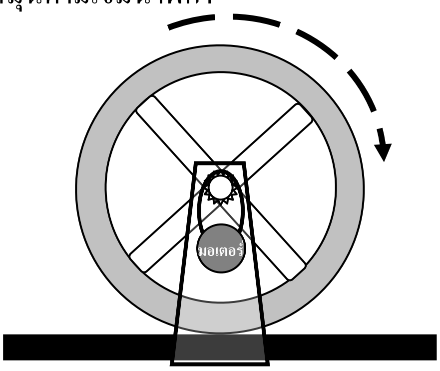
4. ชุดล้อจักรยานติดขนแปรง
5. แผ่นยางและสายพาน
6. มอเตอร์
7. แบตเตอร์รี
8. สายไฟ
9. กระดาษทำนายผล

ภาพแสดงวงล้อขนแปรงและสายพาน

วิธีการและบันทึกผล

กรณีที่1 วงล้อรถจักรยานที่มีขนแปรงติดรอบวงล้อ วางอยู่บนพื้นยางดังรูป แล้วใช้มอเตอร์ขับวงล้อ

ให้หมุนตามเข็มนาฬิกา

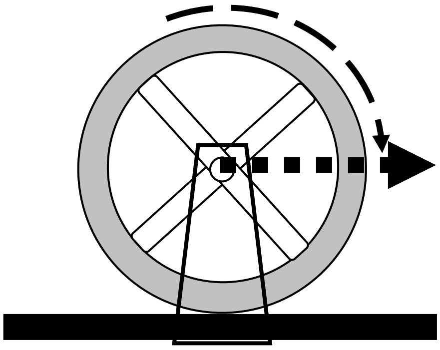


ให้วาดรูปปลายขนแปรงที่เห็น	
ทำนาย	**เฉลย**

มีแรงเสียดทานที่พื้นกระทำต่อปลายขนแปรงหรือไม่ ☐ มี ☐ ไม่มี

ถ้ามี ให้วาดรูปลูกศรแสดงทิศของแรงเสียดทาน

<u>กรณีที่2</u> วงล้อรถจักรยานที่มีขนแปรงติดรอบวงล้อ วางอยู่บนพื้นยางดังรูป แล้วออกแรงผลักแกนกลางของล้อจักยานให้เคลื่อนที่จากซ้ายไปขวา



ให้วาดรูปปลายขนแปรงที่เห็น	
<u>ทำนาย</u>	**<u>เฉลย</u>**

มีแรงเสียดทานที่พื้นกระทำต่อปลายขนแปรงหรือไม่ ☐ **มี** ☐ **ไม่มี**

<u>ถ้ามี</u> ให้วาดรูปลูกศรแสดงทิศของแรงเสียดทาน

สรุป

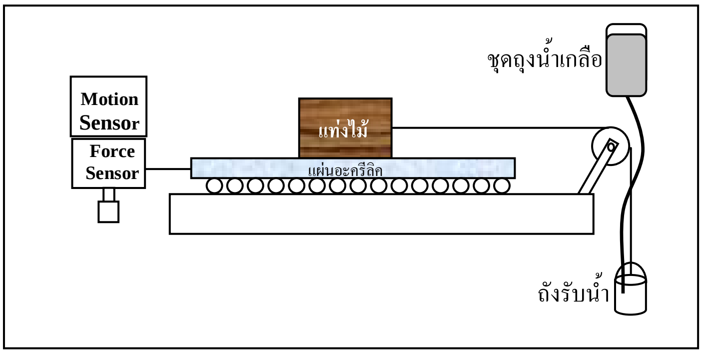
ใบงานที่ 5: ชนิดของแรงเสียดทาน

วัตถุประสงค์

เพื่อให้นักเรียนอธิบายแรงเสียดทานสถิต แรงเสียดทานสถิตสูงสุด และแรงเสียดทานจลน์ได้

อุปกรณ์

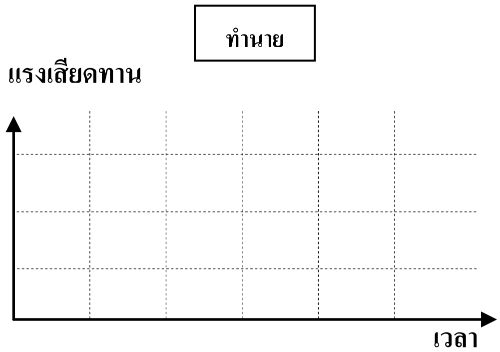
1. แท่งไม้ (10 x 15 x 5 cm.)
2. แผ่นอะครีลิค (15 x 100 x 0.5 cm.)
3. แผ่นไม้ (15 x 150 x 2 cm.)
4. ลูกปืน(ball bearing)
5. Motion Sensor
6. Force Sensor
7. สายเอ็น
8. ชุดถุงน้ำเกลือ
9. ถังรับน้ำ
10. รอก
11. Data Studio Program

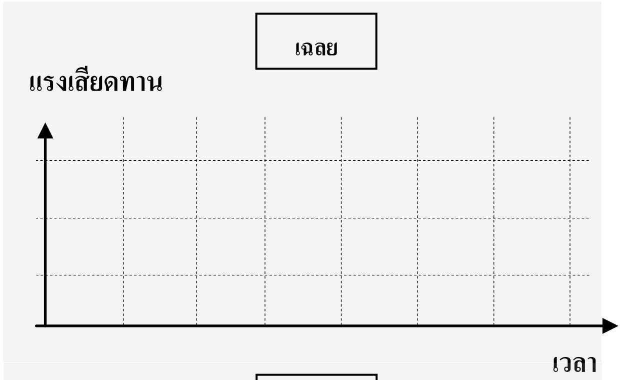


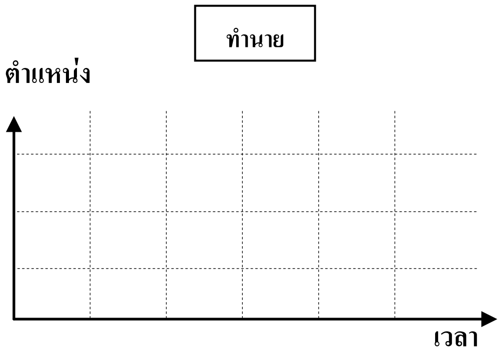
ภาพแสดงอุปกรณ์สาธิตกราฟชนิดแรงเสียดทาน

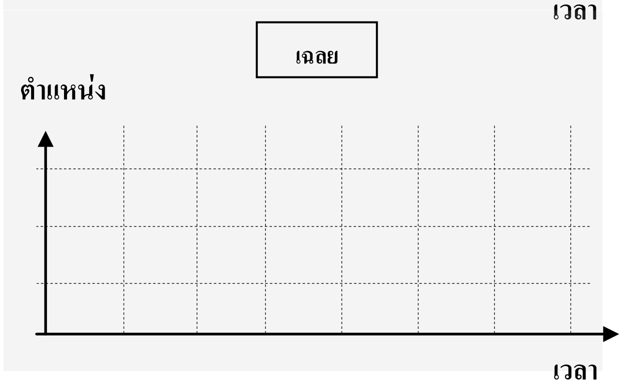
วิธีการและบันทึกผล

1. วาดกราฟตำแหน่งและกราฟแรงเสียดทานที่ผิวแผ่นอะครีลิคกระทำต่อผิวแท่งไม้ เมื่อค่อยๆเพิ่มแรงดึงแท่งไม้ ไปทางขวา จนแท่งไม้เคลื่อนที่









2. เปรียบเทียบกราฟตำแหน่งและแรงเสียดทานที่แผ่นอะครีลิคกระทำต่อแท่งไม้ แล้วตอบคำถามต่อไปนี้

2.1 ในช่วงที่แรงเสียดทานเพิ่มขึ้นอย่างคงที่แท่งไม้ เคลื่อนที่หรือไม่…………………………………………
เรียกแรงเสียดทานชนิดนี้ว่า……………………………………………………………………………………

2.2 เมื่อแรงเสียดทานมีขนาดสูงสุดวัตถุเคลื่อนที่หรือหยุดนิ่ง………………………………………………
เรียกแรงเสียดทานชนิดนี้ว่า……………………………………………………………………………………

2.3 ช่วงที่วัตถุเคลื่อนที่ ขนาดของแรงเสียดทานเป็นอย่างไร………………………………………………..
เรียกแรงเสียดทานชนิดว่า…………………...

สรุป

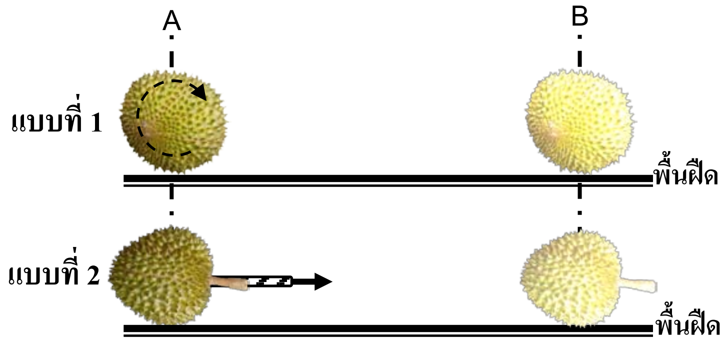
ใบงานที่ 6: ชนิดของแรงเสียดทานการกลิ้ง

วัตถุประสงค์

นักเรียนสามารพแยกแยะแรงเสียดทานสถิต และแรงเสียดทานจลน์เมื่อวัตถุแข็งเกร็งกลิ้งโดยไม่ไถลได้

อุปกรณ์

10. ทุเรียน 2 ลูก
11. แผ่นกระดาษลัง 2 แผ่น



ภาพแสดงการเคลื่อนที่ของลูกทุเรียน

วิธีการและบันทึกผล

ให้นักเรียนอธิบายลักษณะการเคลื่อนที่และร่องรอยของหนามทุเรียนที่ปรากฏบนพื้น ของแต่ละแบบ และสรุปชนิดของแรงเสียดทานระหว่างหนามทุเรียนกับพื้นฝืด

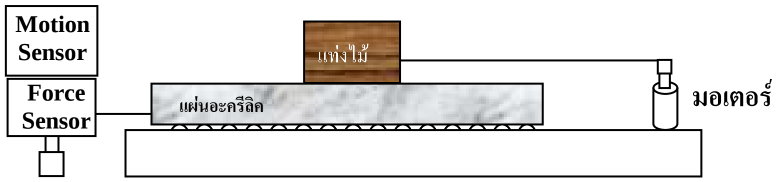
	ทำเครื่องหมาย ✓	**อธิบายร่องรอยการเคลื่อนที่ของลูกทุเรียน**	
		แบบที่1(การกลิ้ง)	**แบบที่ 2(การไถล)**
1. ร่องรอยการเคลื่อนที่ของลูกทุเรียนบนพื้นฝืดใน**แบบที่1** และ **แบบที่2**	☐ **เหมือนกัน** ☐ **ต่างกัน**	…………………………………… …………………………………… …………………………………… ……………………………………	………………………………… ………………………………… ………………………………… …………………………………
2.ชนิดของแรงเสียดทาน		**เรียกว่า**………………	**เรียกว่า**………………

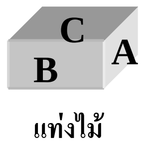
สรุป

ใบงานที่ 7: คุณสมบัติแรงเสียดทาน (1)

วัตถุประสงค์

นักเรียนสามารถอธิบายได้ว่าแรงเสียดทานจลน์ไม่ขึ้นกับขนาดพื้นที่ผิวสัมผัสของวัตถุ

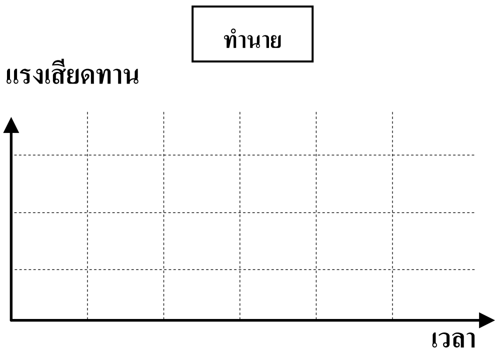


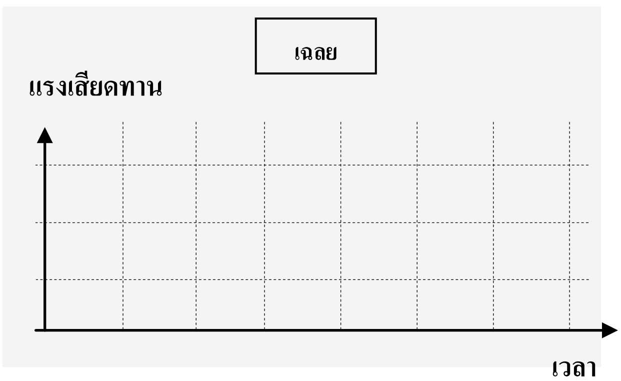


อุปกรณ์

1. แท่งไม้ 2. แผ่นอะคลีลิค 3. แผ่นไม้ 4. Motion Sensor5. Force Sensor 6. สายเอ็น 7. มอเตอร์ 9. Data Studio Program 10. ลูกปืน (barring ball)

1. เขียนกราฟแรงเสียดทานที่ผิวของอะครีลิคกระทำต่อผิวด้านA ด้านB และด้านCของแท่งไม้





2. เปรียบเทียบกราฟแรงเสียดทานที่ผิวของแผ่นอะครีลิคการทำต่อผิวของแท่งไม้ จากข้อ1

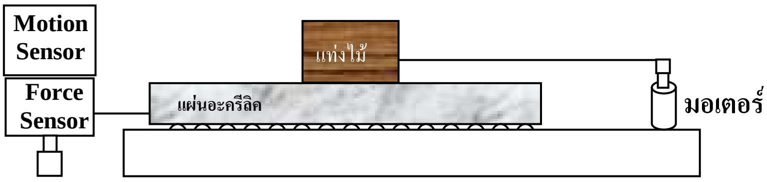
3. สรุป

กิจกรรมที่ 8: คุณสมบัติแรงเสียดทาน (2)

วัตถุประสงค์

นักเรียนสามารถอธิบายได้ว่าแรงเสียดทานจลน์ไม่ขึ้นกับอัตราเร็วการไถลของวัตถุ

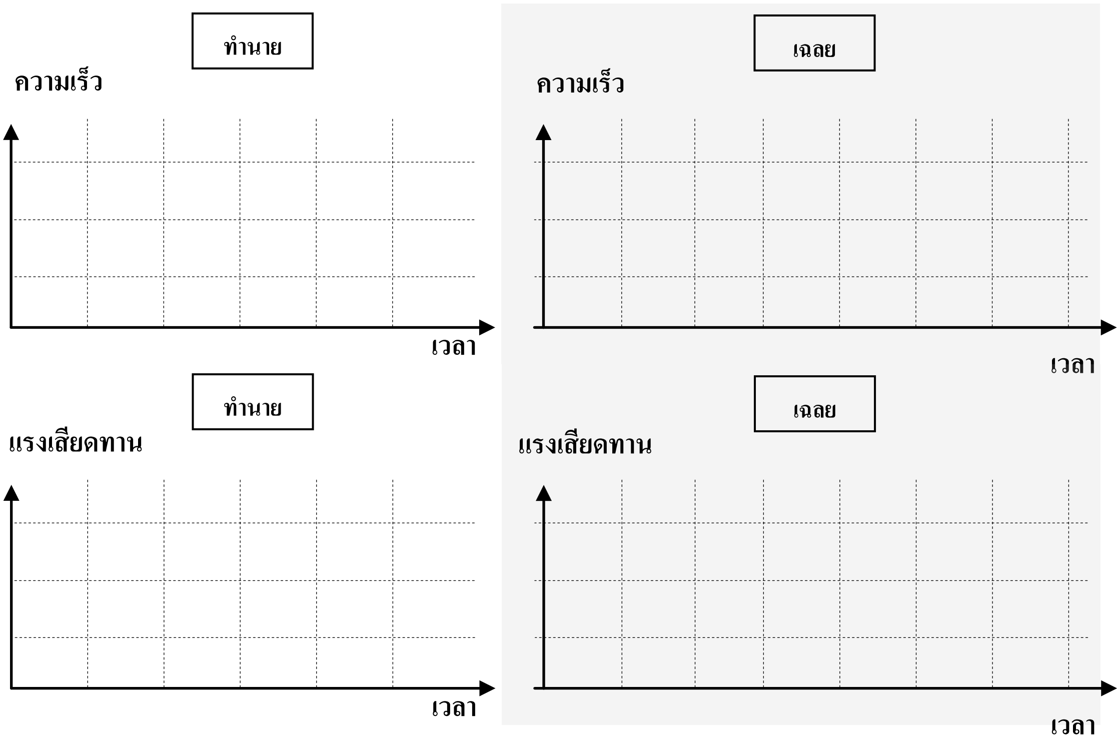
อุปกรณ์



1. แท่งไม้ 2. แผ่นอะคลีลิค 3. แผ่นไม้ 4. Motion Sensor5. Force Sensor 6. สายเอ็น 7. มอเตอร์ 9. Data Studio Program 10. ลูกปืน (ball bearing)

วิธีการและบันทึกผล

1. มอเตอร์ออกแรงดึงแท่งไม้ ไปทางขวาด้วยความเร็วV_1



2. มอเตอร์ออกแรงดึงแท่งไม้ ไปทางขวาด้วยความเร็วV_2 โดย $V_2 > V_1$

3. เปรียบเทียบกราฟ ข้อ1, ข้อ2

3.1 ค่าความเร็ว V_1 ของแท่งไม้……………………………………………………
ค่าแรงเสียดทานที่ผิวแผ่นอะครีลิคกระทำต่อผิวแท่งไม้………………………

3.2 ค่าความเร็ว V_2 ของแท่งไม้………………………………………………………
ค่าแรงเสียดทานที่ผิวแผ่นอะครีลิคกระทำต่อผิวแท่งไม้…………………………

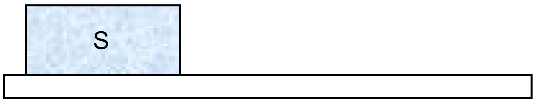
4. สรุปความสัมพันธ์ของความเร็ว (V) ของแท่งไม้ กับแรงเสียดทานที่ผิวของแผ่นอะครีลิคกระทำต่อผิวแท่งไม้

ใบงานที่9: คุณสมบัติแรงเสียดทาน (3)

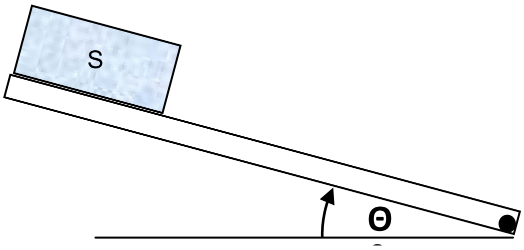
วัตถุประสงค์

เพื่อให้นักเรียนสามารถบอกได้ว่า แรงเสียดทานขึ้นกับวัสดุผิวสัมผัส

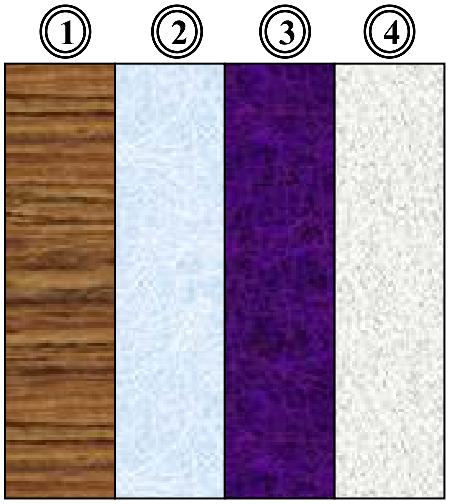
อุปกรณ์



รูป B



รูป C



รูป A

1. แผ่นไม้ 2. แผ่นสังกะสี 3. แผ่นยาง 4. แผ่นกระจก

วิธีการและบันทึกผล

นำแท่งวัตถุ S ที่มีขนาดและมวลเท่ากัน วางบนพื้นวัสดุทั้งสี่ชนิดที่ตำแหน่งเดียวกัน ดังรูปB หลังจากนั้นค่อยๆยกพื้นวัสดุทั้งสี่ชนิดพร้อมกันที่มุมต่างๆ ดังรูปC แท่งวัตถุS บนพื้นวัสดุชนิดใดเคลื่อนที่ก่อนกัน..

เพราะเหตุใด..

สรุป

APPENDIX E
THE SATISFACTION QUESTIONNAIRE ON THE FRICTIONAL FORCE LEARNING MODULE

แบบสำรวจความพึงพอใจต่อกิจกรรมการเรียนการสอน เรื่อง แรงเสียดทาน

ชื่อ..นามสกุล.......................................ชั้น..................

แบบสำรวจนี้ไม่มีผลต่อเกรดและคะแนนของนักเรียน แต่จะเป็นประโยชน์ต่อการพัฒนาการเรียนการสอนเรื่องแรงเสียดทาน จึงขอความร่วมมือให้นักเรียนแสดงความคิดเห็นต่อข้อความข้างล่างตามระดับความคิดเห็นระหว่าง 1 (ไม่เห็นด้วยอย่างยิ่ง) ถึง 5 (เห็นด้วยอย่างยิ่ง) ที่ส่งเสริมให้นักเรียนเข้าใจเนื้อหาเรื่องนี้ โดยใส่เครื่องหมายลง ✓ ตามระดับความคิดเห็นต่อไปนี้

1: ไม่เห็นด้วยอย่างยิ่ง	2: ไม่เห็นด้วย	3: ปานกลาง	4: เห็นด้วย	5: เห็นด้วยอย่างยิ่ง

ข้อ	วิธีการต่อไปนี้ช่วยให้นักเรียนเข้าใจเนื้อหาเรื่อง แรงเสียดทาน	ระดับความพึงพอใจ				
		1	2	3	4	5
1	การมีชุดสาธิตประกอบการสอน					
2	การให้ใบกิจกรรม(หรือใบงาน)ประกอบการเรียนการสอน					
3	การให้ร่วมงานเป็นกลุ่มและแลกเปลี่ยนความคิดเห็นกับเพื่อน					
4	การให้มีการทำนายเหตุการณ์ก่อนและตามด้วยการสาธิตจริง					
5	การยกตัวอย่างเชื่อมโยงกับเหตุการณ์จริง					

6.วิธีการเรียนการสอนแบบอื่นๆ ที่นักเรียนคิดว่าช่วยส่งเสริมความเข้าใจได้ดีขึ้น

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7. ความพึงพอใจต่อการเรียนการสอนในครั้งนี้ (เขียนอธิบายพร้อมยกตัวอย่าง)

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ขอขอบคุณในความร่วมมือ

BIOGRAPHY

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