Development of a Multiple-Choice Test on the Concept of Friction Force Direction

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Abstract

The conception of the direction of friction force would fit into the idea that "the direction of friction force acting on an object is opposite to the relative motion of the object with the surface". For high-school students, this definition is sometimes simplified to several versions, such as opposite to the object's motion, opposite to an exerted force, or opposite to the object's acceleration, which leads to many misconceptions. To detect the misconception that could occur in high-school students, a conceptual multiple-choice test on the direction of friction force was created. The test consists of 16 items covering seven misconceptions: Friction is (1) always opposite to the direction of the motion, (2) in the same direction as motion, (3) always opposite to the direction of the external force, (4) in the same direction as the applied force, (5) always opposite to the direction of acceleration, (6) always horizontal, and (7) always opposite to the direction of rotational motion. After the designed questions were assessed with a sample group of 637 grade 11–12 science and math students from three schools, it was found that most of the items fell within the acceptable range of classical test analysis but received a low Cronbach's alpha value of 0.46. However, the test provides more insightful information when analyzed based on the choices students make.

Keywords: Conceptual Test, Direction of Friction, Friction Force, Multiple-Choice Test, Physics Concept

Introduction

A general definition suggests that the friction force is a force associated with the relative motion between surfaces (Serway & Jewett, 2004; Knight, 2017). Although the concept appears simple, understanding it is not easy. Several misconceptions related to the friction force have been reported. In the work of Kızılcık et al. (2021), up to 42 different misconceptions were found, including seven related to the direction of friction force. In Thailand, Prasitpong and Chitaree (2010) also reported misconceptions about friction force among high-school students, some of which match the misconceptions identified by

Kızılcık et al. (2021).

One powerful tool to assess misconceptions for improving instruction is the conceptual multiple-choice test. Several existing tests on frictional force have been developed, such as the one by Besson, Borghi, De Ambrosis, and Mascheretti (2010). Another was developed by Cari, Wulandari, Aminah, Handhika, and Nugraha (2019). Chia (1996) also created one, and in Thailand, there is the work of Prasitpong (2012). However, most existing conceptual multiple-choice tests cover various aspects of friction, such as type, magnitude, and direction, all in one test. The problem lies in the fact that each aspect can contain various models of misconceptions. Kızılcık et al. (2021) also mentioned this in the suggestions of their work: whoever wants to create a conceptual multiple-choice test for the friction force next should focus on one aspect rather than covering everything in a single test.

In Thailand, there have been a few reports about developing the friction force conceptual multiple-choice test. The recent one was from the work of Prasitpong (2012), which still covers various aspects. Hence, the determination to create a conceptual test focusing on only one aspect of friction force was motivated. This study focuses on the aspect of the direction of friction.

Objective

To develop a conceptual multiple-choice test that can probe misconceptions about the direction of friction among high-school students.

Concept theory framework

1. The concept of friction force

In the work of Develi and Namdar (2019), the authors conducted a review of physics books to determine the appropriate concept for frictional force. Their study concludes that the concept of friction force can simply be stated as "a force that prevents sliding" (Develi & Namdar, 2019, p. 97). However, it is emphasized in the paper that this is a briefly simplified concept. The true cause of friction force lies on a microscopic scale, involving the bonding of molecules between the object and the surface. In the general case, to find the direction of friction, a common statement, "the friction force on an object is opposite to its motion or impending motion relative to the surface" (Serway & Jewett, 2004, p. 133), is usually used. This similar common statement is also mentioned in Knight (2017).

2. Alternative concepts of the direction of the friction force

Kızılcık et al. (2021) studied the alternative concepts of friction force by gathering 42 associated papers. For the aspect of the direction of the friction force, they reported a list of misconception models as shown in Table 1, which in this paper will be referred to by the abbreviated names.

Table 1: Misconception models about the direction of the friction force

The misconception models	Description (Kızılcık et al., 2021)
Opposite to Motion	Friction is always opposite to the direction of the motion.
Same with Motion	Friction is in the same direction as the object's motion.
Opposite to External Force	Friction is always opposite to the direction of the external force.
Same with External Force	Friction is in the same direction as the applied force.
Opposite to Acceleration	Friction is always opposite to the direction of the object's acceleration.
Always Horizontal	There is no friction force in the vertical direction. Friction is always horizontal.
Opposite to Rotational Motion	Friction is always opposite to the direction of rotational motion.

3. Conceptual multiple-choice tests

"Effective instruction requires more than dedication and subject knowledge; it requires technical knowledge about how students think and learn" (Hestenes, Wells, & Swackhamer, 1992, p. 2). Several approaches can be applied to assess students' knowledge or concepts. One of the most effective methods is interviewing students; however, this process is time-consuming and requires considerable effort (Thongchai, 2009; Hestenes et al., 1992; Engelhardt, 2009).

An alternative approach has been created: the conceptual multiple-choice test. The conceptual multiple-choice test can be designed to prove students' underlying concepts. They can emphasize conceptual reasoning and reveal common misconceptions held by students. In the field of physics education, several well-known conceptual multiple-choice tests have been developed. The Force Concept Inventory (FCI) (Hestenes et al., 1992) is one of the most frequently mentioned. Other notable conceptual multiple-choice tests include the Force and Motion Conceptual Evaluation (FMCE) (Thornton & Sokoloff, 1998), the Energy and Momentum Conceptual Survey (EMCS) (Singh & Rosengrant, 2003), etc. These conceptual multiple-choice tests are typically designed for specific physics topics, and most are limited to probing only the concepts they were originally designed to assess.

Engelhardt (2009) has examined the typical methods used to create conceptual multiple-choice tests. The steps can be summarized as follows:

1. Recognize the need for the test: Determine the problem or the need for developing a new conceptual multiple-choice test.
2. Formulate the objectives: Clearly define the instructional objectives related to the domain of knowledge.
3. Construct test items: Develop test items carefully and thoughtfully.
4. Content validation (should be checked with Steps 2 and 3): Ensure the test content is valid, meaning it accurately measures the intended concepts.
5. Reliability check (should be checked with Step 3): Various analyses are conducted to evaluate its reliability. These include basic statistical analysis, item analysis, and reliability testing, such as internal consistency measures like Cronbach's alpha.
6. Distribution: The complete and finalized test is reported for use.

Thongchai (2009) also follows a similar process in developing his conceptual survey on mechanical waves. His development test process is based on the framework proposed by Crocker and Algina (1986). The test in this study was developed using a process like Engelhardt (2009).

Materials and Methods

1. Forming a test

In designing the test, 16 items were assigned to cover seven misconception models from Kızılcık et al. (2021). Some items were sourced from existing friction force concept tests, and some were newly created, ensuring they trigger the targeted misconceptions. Since the test focuses on direction, all items share the same choices: directional arrows (⟶, ⟵, ↑, ↓, ↖, ↘), "There is no friction force," and "Other".

2. Test validation

The content validation was conducted by physics experts at Mahidol University, while the clarity validation was conducted by a sample group in the pilot study to ensure that test-takers correctly understand the questions.

3. Sample group

The test was administered to 637 Grade 11–12 science and math students from three schools. All of them had already studied friction forces in Grade 10. The research was conducted during physics classes. The researcher guided the students on the rules for taking the test and provided a 2B pencil or eraser if needed. The test took 25–30 minutes to complete and required no calculations. Students were not provided with the answers by the researcher until every student in the sample group had completed the test.

4. Data analysis

The test's quality was assessed using the Difficulty Index, Discrimination Index, and Cronbach's Alpha. The Difficulty Index measures how easy an item is; 0.3–0.8 is the acceptable range (Hernandez, 2009). Discrimination Index evaluates how well an item differentiates high-ability and low-ability students; values above 0.24 are acceptable (D'Sa & Visbal-Dionaldo, 2017). Cronbach's Alpha measures test reliability and internal consistency. It should be more than 0.7 (Tongchai, 2009).

Results

1. The test

The last version of the test consists of a total of 16 items. The references come from the following sources: The direction of friction force worksheet used in first-year Physics at Mahidol University (Emarat & Arayathanitkul, 2022), Besson et al. (2010), Prasitpong and Chitaree (2010), and Cari et al. (2019). Each item is assigned to a misconception listed in Table 2.

Table 2: The misconception models and their items

The misconception models	items
Opposite to Motion	5, 13
Same with Motion	2, 3, 10
Opposite to External Force	6, 14
Same with External Force	1, 7*
Opposite to Acceleration	4
Always Horizontal	7*, 8
Opposite to Rotational Motion	9, 11, 12, 15, 16

*Item 7 was originally intended for the "Always Horizontal" model, but it was later determined that it could also be used to assess the "Same with External Force" model.

All items follow the same design pattern: determining the misconception model to probe, using a trigger related to that misconception, and providing the choice that students with that misconception are likely to select.

To illustrate this, item 7 from the "Always Horizontal" misconception model will be explained as an example. The situation for item 7 is shown in Figure 1a. It presents a simple scenario where a box is being held against a wall. The trigger in this case is that the object can only move vertically rather than horizontally, which is an unusual setup in frequent problem exercises. If a student holds the "Always Horizontal" misconception model, they will select the choice "There is no friction force".

Another example is item 1 from the "Same with External Force" model. Figure 1b shows the scenario for this item, where a box is being pushed by an applied force, but the box has not yet started moving. The trigger here is the applied force. If a student holds the "Same with External Force" misconception model, they will choose the option that represents the direction in which the force is exerted.

The full test in the Thai language can be accessed from reference #19.

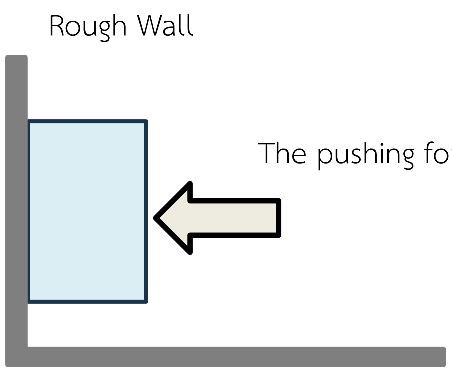

Figure 1a: Item 7

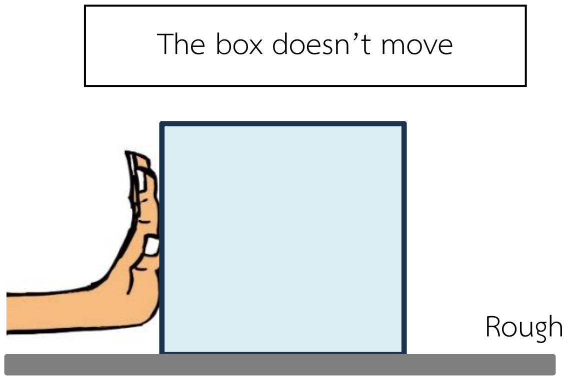

Figure 1b: Item 1

Figure 1: Examples of the situation in the test.

2. **Classical test theory analysis**

The bar graph of the Difficulty Index and Discrimination Index is shown in Figures 2 and 3, respectively. The two indices were attained from analyzing the data of the sample group.

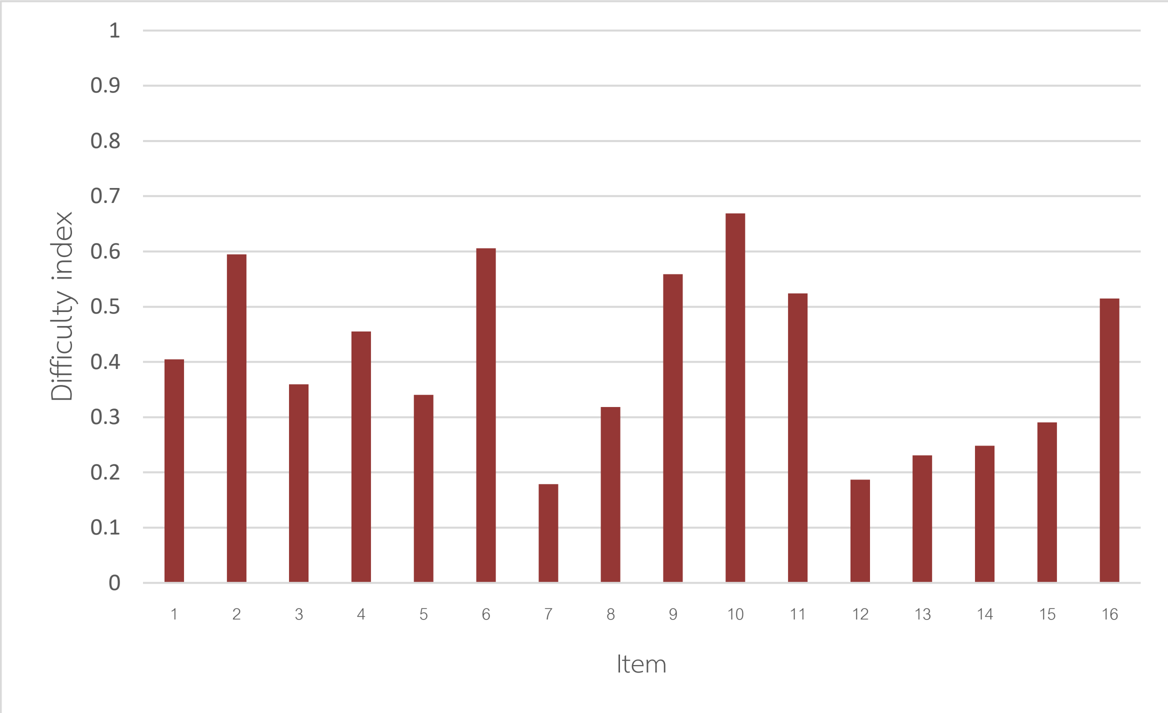

Figure 2: The bar plot of the Difficulty Index value of each item.

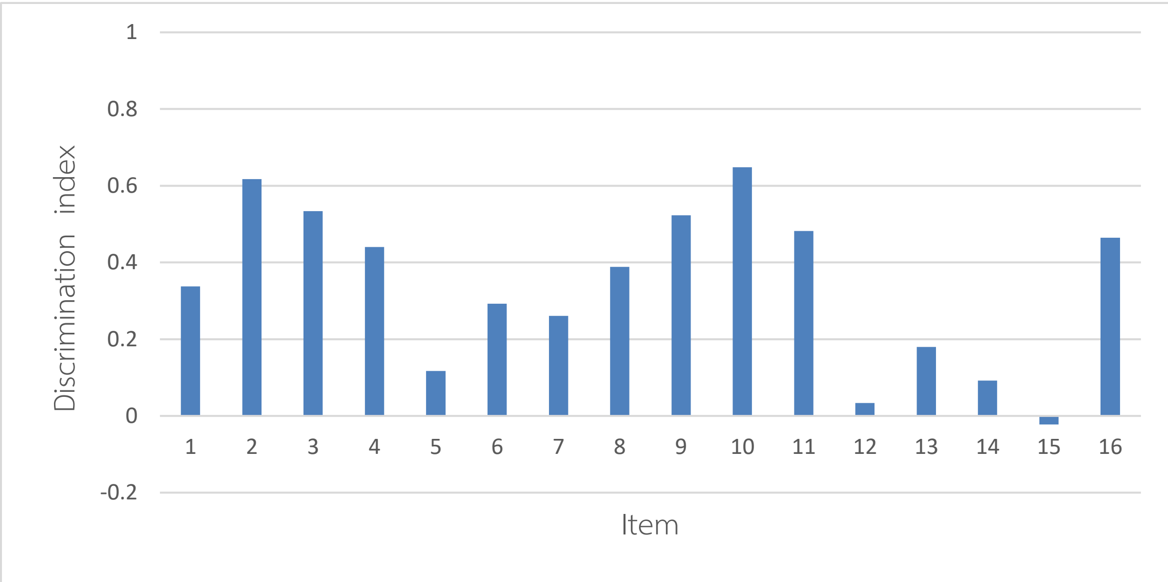

Figure 3: The bar plot of the Discrimination Index value of each item.

It can be seen from Figure 2 that most items had appropriate values, except for items 7, 12, 13, 14, and 15, which had low difficulty values. This can be explained by the nature of item 7, which involves the “Same with External Force” and “Always Horizontal” misconceptions. It triggers multiple concept models, resulting in distinct types of responses, leading to low correctness. Similarly, for items 12–15, many students were affected by the “Opposite to Motion” misconception, causing them to select incorrect answers and contributing to low correctness. Additionally, Items 5, 12, 13, 14, and 15 had poor discrimination index values (see Figure 3). This can be attributed to the fact that low-ability students often answered items 5, 14, and 15 correctly due to the “Same with Motion” misconception, which unintentionally led them to the correct choice. In the case of item 12, both high-ability and low-ability students applied the same misconception, “Opposite to Motion”, leading to consistently low correctness and poor discrimination.

For the test reliability, Cronbach’s Alpha had a value of 0.46, indicating poor internal consistency, which was expected due to the test measuring seven different misconceptions.

3. Using the test to assess students' understanding

This analysis aims to provide an overview of the statistical results for the groups of items assigned to each misconception. The mean percentage is the average of the scores in each misconception model divided by the full scores of that group and multiplied by 100. The SD percentage is the standard deviation of the average scores converted into a percentage. The SE percentage, which is the standard error of the average scores, is also converted into a percentage. The result is shown in Table 3.

Table 3: The basic statistics of each misconception model

Misconception model	Mean %	SD %	SE %
Opposite to Motion	28.6	33.5	1.3
Same with Motion	54.1	36.2	1.4
Opposite to External Force	42.7	30.5	1.2
Same with External Force	29.2	33.0	1.3
Opposite to Acceleration	45.5	49.8	2.0
Always Horizontal	24.9	33.4	1.3
Opposite to Rotational Motion	41.5	20.1	0.8

Most students struggle with the “Opposite to Motion,” “Same with External Force,” and “Always Horizontal” misconceptions, as shown by their low mean percentages.

In a deeper examination by checking the choices that students tend to choose, the “Opposite to Motion” misconception model is expected, as students frequently choose the direction opposite to the object's motion.

For the “Always Horizontal” model, most students were incorrect because they selected "There is no friction force," which is associated with the “Always Horizontal” misconception.

For the “Same with External Force” model, an interesting concern emerged, particularly in item 1 (see Figure 1b). This item was designed to capture the “Same with External Force” misconception. Surprisingly, instead of selecting the direction that is the same as the external force, students tended to choose "There is no friction force". This trend contributed to a lower correctness percentage.

To explain this, one assumption arises: "Because there is no visible motion, students might assume that there is no friction force". If this explanation is true, a concerning issue will emerge in item 7 in Figure 1a, which also falls under the “Same with External Force” misconception model. However, the concern here is not about the “Same with External Force” misconception because, in item 7, the option indicating the same direction as the external force still existed and was selected by a considerable number of students. The real concern lies in the perspective of the “Always Horizontal” model. The question arises whether students chose "There is no friction force" in this item due to the “Always Horizontal” misconception or if they were influenced by a newly observed misconception, which could be called “No Motion, No Fiction.”

Conclusions and Discussion

In this conceptual multiple-choice test development, the approach of probing the seven misconceptions based on Kızılcık et al. (2021) which are Friction to be (1) always opposite to the direction of motion, (2) in the same direction as the motion, (3) always opposite to the direction of the external force, (4) in the same direction as the applied force, (5) always opposite to the direction of acceleration, (6) always horizontal, and (7) always opposite to the direction of rotational motion, resulted in 16 items. These 16 items passed the content validation from physics experts at Mahidol University and were confirmed for clear readability through testing with a pilot sample group. After being administered to the target group, the results showed that most items fell within the acceptable range for the Difficulty Index and Discrimination Index. The items that fall outside the acceptable range are still not a problem since these indices only consider the correct answer, while this test is designed to analyze the choices students select instead. Therefore, the Difficulty Index and Discrimination Index are not entirely suitable for judging the problem. Additionally, since classical test theory has limitations due to its indices being dependent on the sample, applying this test to a different group might yield different results. Therefore, considering the use of the Rasch model may be more suitable for further analysis.

Another discussion point is in using the test to assess students' understanding. The high-school students from the sample group tend to have the "Opposite to Motion," "Same with External Force," and "Always Horizontal" misconceptions, shown by the mean percentage scores that are lower than others. However, caution is needed when interpreting the results for the "Same with External Force" and "Always Horizontal" models. The low percentage of correctness in these two groups might be due to a hidden misconception, which can be called "No Motion, No Friction." This misconception relates to the phrase "there is no friction force if the object does not move." In the further development of the test, considering modifications of the "Always Horizontal" items, including the movement to the objects could be a more effective way to reduce this 'No Motion, No Friction' misconception effect.

Therefore, the test needs further development. While using the current version of the test with the sample group, the author found that several items were still not appropriate. For example, items in the "Opposite to Rotational Motion" model may be removed from the test since high-school students in Thailand do not encounter this situation frequently in their curriculum. Additionally, the "Opposite to Acceleration" model may need more items added to ensure greater confidence in assessing this misconception. These issues will be revised to create a new and improved version.

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