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Sex and Grade Issues in Influencing Misconceptions about Force and Laws of Motion: An Application of Cognitively Diagnostic Assessment

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The force and laws of motion concept is a key concept for learning mechanics and comprehending other complex concepts in physics. If students possess misconceptions about this concept, learning mechanics will be meaningless, which could lead to failure in physics learning. Sexes and grades may influence students' misconceptions. However, there are contradictory findings regarding their effects on students' misconceptions. In this study, we diagnosed misconceptions about force and laws of motion in 522 Thai high schoolers using the cognitively diagnostic assessment. Misconceptions about force and laws of motion comprise six attributes, i.e., (1) resultant force, (2) Newton's first law of motion, (3) Newton's second law of motion, (4) Newton's third law of motion, (5) frictional force, and (6) gravitational force. In addition, we compared the proportional differences among students of different sexes and grades who possessed misconceptions about each attribute of force and laws of motion. The results showed that the percentage of high schoolers who possessed misconceptions was high for all six attributes. There was a significant difference in the proportion of male and female students who possessed misconceptions about resultant force. Moreover, there were significant differences in the proportions of students of different grades who possessed misconceptions about resultant force and Newton's second law of motion. The research findings suggested teachers should develop remedial programs to correct their high schoolers' misconceptions about force and laws of motion for all six attributes.

Keywords: cognitively diagnostic assessment, force and laws of motion, sex, grade, misconception, sequential bug-G-DINA model

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INTRODUCTION

The force and laws of motion concept is a key concept for learning mechanics and comprehending other complex concepts in physics, such as electricity, heat, and waves (Tomara et al., 2017). If students hold misconceptions about force and laws of motion, learning mechanics will be meaningless. Furthermore, they will not be able to apply the concept of force and laws of motion to other physics concepts. As a result, students will not be able to achieve learning goals, which could eventually lead to failure in physics learning (Aini et al., 2021; Gurel et al., 2015).

Students' backgrounds (i.e., sex and grade) have been some factors contributing failure in physics learning. However, there are conflicts in the findings of their effects on students' misconceptions. Some studies found that male students had fewer misconceptions than their female counterparts at both the high school (Fratiwi et al., 2020) and university levels (Bates et al., 2013). Other studies, on the other hand, indicated that there were no differences between male and female university students when it comes to students of different sexes having misconceptions (Al-Rsa'i et al., 2020; Azman et al., 2013). As for grade, some studies showed that university students of higher years had fewer misconceptions about force and laws of motion than those of lower years (Suprapto et al., 2016). In other words, the number of misconceptions decreased as students move up their educational levels (Mufit, 2018). Other studies revealed that there were no differences among high school students of different age groups when it comes to developing misconceptions (Bouzid et al., 2022). That is, students of all ages possessed the same patterns of misconceptions about force and laws of motion (Liu & Fang, 2016).

These studies used the Force Concept Inventory (FCI; Hestenes et al., 1992) to diagnose students' misconceptions about force and laws of motion and total scores to compare the differences. That is, they analyzed data from the FCI using the classical test theory (CTT), which provided scores for students' misconceptions as a single continuous value. This may result in contradictory research findings, as background differences may contribute to the proportional differences in students having misconceptions about some attributes of force and laws of motion. To provide more information of misconceptions obtained from the FCI, a subscore strategy was used to diagnose misconceptions. The subscores were calculated by counting the number of times an option measuring each misconception was chosen by a student. However, a standard setting must be performed on the subscores obtained to identify if a student has misconceptions or not. This is because the subscores cannot provide direct diagnostic information about students having misconceptions (Bradshaw & Templin, 2014).

To provide direct diagnostic information, we can use cognitive diagnostic models (CDMs) to analyze students' responses. CDMs are a family of psychometric models developed to provide categorical classifications of misconceptions for multiple attributes using item responses. Students with the same total score according to the CTT can have different attribute patterns, which provide additional information of students' strengths and weaknesses that are valuable as a guidance for teaching and learning. Therefore, CDMs are recognized as psychometric models that provide more fine-grained information than other models and are adopted today as interest in it continues to grow (Ma & de la Torre, 2016; Paulsen & Valdivia, 2021).

CDMs are psychometric models for cognitively diagnostic assessment (CDA). CDA is a type of educational assessment designed to diagnose specific knowledge structures or predetermined set of attributes to provide fine-grained diagnostic information to individual students about their strengths and weaknesses. Moreover, CDA can provide useful information to teachers that helps them plan their instructions and develop remedial programs. Importantly, CDM is used to extract diagnostic information from students' responses (de la Torre & Minchen, 2014; Javidanmehr & Sarab, 2017). We, therefore, diagnosed high schoolers' misconceptions about force and laws of motion using CDA and compared the proportions of students of different sexes and grades who developed misconceptions about each attribute of force and laws of motion. The research findings offer insights into the effects of sex and grade on each attribute of misconceptions about force and laws of motion. Thus, this detailed information is used to design remedial programs to correct students' misconceptions in accordance with their backgrounds. In other words, remedial programs are developed to be relevant to students' needs.

In the following section, we briefly presented a review of relevant literature, i.e., cognitively diagnostic assessment (CDA), and misconceptions about force and laws of motion.

Literature Review

Cognitively Diagnostic Assessment (CDA)

The CDA is an approach that integrates cognitive psychology into psychometric modelling. The CDA is a type of educational assessment designed to diagnose specific knowledge structures or predetermined set of attributes to provide fine-grained diagnostic information about the strengths and weaknesses extracted by CDMs to an individual student. It also provides invaluable information to teachers that helps them plan their instruction and develop remedial programs (de la Torre & Minchen, 2014; Javidanmehr & Sarab, 2017).

The CDA process is comprised of five major steps, i.e., (1) defining the purpose of the assessment, (2) identifying and validating attribute specifications, (3) constructing and validating the Q-matrix, (4) selecting CDMs for data analysis, and (5) reporting assessment results. Each step contains details as follows: (Javidanmehr & Sarab, 2017; Ravand & Baghaei, 2020)

1) Defining the Purpose of the Assessment

The first step of CDA is to clearly define the purpose of the assessment that properly describes the attributes to be assessed. Moreover, teachers should identify the number of given attributes and their levels, such as students' possession of misconceptions or correct concepts.

2) Specifying and Validating Attribute Specifications

The second step is to identify a set of attributes assessed in a test and attribute specifications by determining hierarchical relationships among attributes, known as a cognitive model. A cognitive model or an attribute specification demonstrates students' thinking process as they are doing the test (Ketterlin-Geller et al., 2019). The construction of a cognitive model requires a consideration of the hierarchical relationships among attributes in accordance with relevant theories and research findings. The hierarchical relationships in the cognitive model will function as a guideline for constructing a Q-matrix. After constructing the cognitive model, the model is validated and corrected. There are three methods to validate the cognitive model, i.e., (a) think-aloud protocols, (b) eye-tracking studies, and (c) an expert panel.

3) Constructing and Validating the Q-matrix

After specifying details of assessed attributes, a tentative Q-matrix is constructed by considering the relationships among attributes in the cognitive model. Then, the Q-matrix is reviewed by subject-matter experts to determine the accuracy and suitability of the Q-matrix construction. After revising the tentative Q-matrix according to experts' suggestions, test items are created using information in the matrix. After that, the Q-matrix is validated and adjusted. There are three methods to validate the Q-matrix, i.e., (a) think-aloud protocols, (b) an expert panel, and (c) an empirical data analysis based on the CDMs. Developing the Q-matrix is an iterative process that needs repeated revisions until satisfactory results are obtained. That is, until a complete Q-matrix is obtained.

A Q-matrix is a table that indicates the attributes measured by each item. It contains the items in the rows and the attributes in the columns. Its entries contain 1 and 0, indicating an attribute is or is not measured by an item, respectively. Each item can measure a single attribute or multiple attributes. An example of a Q-matrix is showed in Table 1. Constructing the Q-matrix requires three steps as follows: (Cai et al., 2018; Chin et al., 2021)

Table 1
An example of a Q-matrix

Item	Attribute 1	Attribute 2	Attribute 3
1	1	0	0
2	1	1	0
3	1	0	1
4	0	1	1
5	1	1	1

3.1) Constructing an Incidence Matrix. The incidence matrix represents a set of potential items used to measure all combinations of attributes when they are independent. It is a K x I matrix, where K is a number of attributes and I is a number of potential items. The total number of potential items is 2^K - 1, excluding the item that do not measure any attributes. Its entries are only 1 and 0, with the former indicating attributes in the rows are measured and the latter indicating attributes in the rows are not.

3.2) Constructing a Reachability Matrix. The reachability matrix represents direct and indirect relationships among attributes specified in the cognitive model. It is a square matrix (*K* x *K*, where *K* is a number of attributes) that contains the attributes in both rows and columns. It contains only entries 0 and 1, and diagonal entries are all equal to 1. That is, if particular attributes listed in the rows have direct or indirect relationships with those in the columns, they are designated with entry 1.

3.3) Constructing a Reduced Q-matrix. The reduced Q-matrix represents all potential items that satisfy the specified relationships among attributes in the cognitive model. It is obtained by removing items that are not in line with the principle of the reachability matrix from the incidence Q-matrix. The Q-matrix used as a guideline for item creation must transpose the reduced Q-matrix in order to get the new Q-matrix that contains the items in the rows and the attributes in the columns.

4) Selecting CDMs for a Data Analysis

In the fourth step, students' responses to test items are analyzed. The chosen CDM that appropriate to data as well as target attributes and the completed Q-matrix are used to estimate item and examinee parameters, i.e., the attribute profiles, and students' mastery status in each attribute. The parameter estimation differs across CDMs that are employed for the analysis.

CDMs can be divided into two types, i.e., (a) dichotomous CDMs for a dichotomous responses analysis, and (b) polytomous CDMs for a polytomous responses analysis. In this study, we analyzed students' responses by using the sequential process model, as this model allowed us to directly diagnose misconceptions (Ma et al., 2021). The sequential process model is a polytomous CDM that is used to analyze graded responses. The model divides students according to successive steps which they solve each item. That is, students who fail the first step are classified into zero category or obtained a score of 0. They are classified into the first category or obtained a score of 1 if they solve the first step successfully but fail the second step, and so forth. As a result, there are H + 1 ordered categories if an item has H steps to solve. The probability of student i with the attribute pattern α_c obtaining a score of h on item j can be expressed as

$$P(X_{ij} = h|\alpha_c) = [1 - S_j(h+1|\alpha_c)] \prod_{x=0}^{h} S_j(x|\alpha_c),$$

where $S_j(h|\alpha_c)$ is the processing function that represents the probability of student i with the attribute pattern α_c performing category h of item j correctly after he or she has performed category h - 1 successfully. The processing function, which acts as item parameter, can be defined using any dichotomous CDM (Ma & de la Torre, 2016). In this study, we used the G-DINA model (de la Torre, 2011) as the processing function to diagnose misconceptions. We refer to this model as the sequential bug-G-DINA.

A Q-matrix used to analyze the polytomous responses is a category-level Q-matrix (Q_c-matrix). The Q_c-matrix contains categories for each item that exclude category 0 in the rows and the assessed attributes in the columns. Its entries are 1 and 0, with 1 indicating an attribute is measured and 1 indicating an attribute is not. The Q_c-matrix can be divided into two types, i.e., a restricted Q_c-matrix and an unrestricted Q_c-matrix. The construction of a restricted Q_c-matrix must take into account the association between attributes and categories. The construction of an unrestricted Q_c-matrix does not require such an association. It can be reasonably assumed that all attributes measured by an item are required by each category of that item (Ma & de la Torre, 2016). Examples of the restricted Q_c-matrix and the unrestricted Q_c-matrix are showed in Table 2 and 3, respectively.

Table 2
An example of the restricted Q_c-matrix

Item	Category	Attribute 1	Attribute 2	Attribute 3
1	1	1	1	0
1	2	0	0	1
2	1	1	0	0
2	2	0	1	0
3	1	0	0	1
3	2	1	0	0

Table 3
An example of the unrestricted Q_c-matrix

Item	Category	Attribute 1	Attribute 2	Attribute 3
1	1	1	1	1
1	2	1	1	1
2	1	1	1	0
2	2	1	1	0
3	1	1	0	1
3	2	1	0	1

5) Reporting Assessment Results

The CDA's final step is to report the mastery profile for each attribute to students according to a data analysis using the CDM. The score reports could be customized for each student by including information about the students' mastery status of each attribute, attribute profile, strengths, weaknesses, and recommended remedial programs. Moreover, the reports should be presented in graphics and written accounts.

Misconceptions about Force and Laws of Motion

Misconceptions are false ideas contradicting proven scientific explanations that impede learning (Desstya et al., 2019; Prodjosantoso et al., 2019). Students develop misconceptions about force and laws of motion that seem logical to them from their own experiences in everyday life (Al-Rsa'i et al., 2020). Wancham et al. (2022) synthesized and categorized common misconceptions about force and laws of motion held by students in secondary and tertiary education. They grouped 27 misconceptions into six categories based on the force and laws of motion topics, which were (1) resultant force, (2) Newton's first law of motion, (3) Newton's second law of motion, (4) Newton's third law of motion, (5) frictional force, and (6) gravitational force. The misconceptions in each category are showed in Table 4. Moreover, they examined hierarchical relationships among these categories or attributes to construct the cognitive model of force and laws of motion. They found that students who held misconceptions about resultant force and Newton's first law of motion could hold misconceptions about Newton's second law of motion. They could also possess misconceptions about frictional force and gravitational force. Newton's third law of motion, however, had no hierarchical relationship with other attributes.

Table 4
Misconceptions about force and laws of motion

Category	Misconception
1. Resultant force	1.1 An object moves in the direction of the greater force. 1.2 An object changes its direction in the direction of the last force.
2. Newton's first law of motion	2.1 An object stores an applied force into an impetus to keep the object going after the force is worn out. 2.2 An impetus keeps objects moving. 2.3 A trajectory of an object depends on an impressed impetus.
3. Newton's second law of motion	3.1 If there is no motion, there is no force acting on an object. 3.2 A moving object stops when the force is stopped. 3.3 If there is motion, there is a force acting on an object in its direction of motion. 3.4 If there is a force acting on an object at rest, the object will move. 3.5 When an object is moving, there is a force in the direction of its motion. 3.6 There is a linear relationship between force and velocity. In other words, a constant velocity results from a constant force. 3.7 An object that moves with a constant acceleration requires a constantly changing force. 3.8 Forces are caused by living or moving things. 3.9 Forces can only be caused by something touching an object.
4. Newton's third law of motion	4.1 An action-reaction pair of force acts on the same object. 4.2 According to applied forces between two objects, the greater mass exerts the greater force. 4.3 According to applied forces between two objects, the bigger object exerts the greater force. 4.4 According to applied forces between two objects, the most active object exerts the greater force. 4.5 When an object moves into an obstacle, the obstacle redirects or stops motion but it cannot be the agent of an applied force.
5. Frictional force	5.1 Frictional force acts on an object when it moves. 5.2 Frictional force always acts opposite to the direction of motion. 5.3 Static frictional force is minimum when an object begins to move. 5.4 Static frictional force is constant and equals to a coefficient of static friction multiplied by a normal force.
6. Gravitational force	6.1 For free fall, a heavier weight causes a bigger acceleration. In other words, heavier objects fall faster. 6.2 There is the gravitational force acting on an object when it is only on the earth. 6.3 The gravitational force has constant value and is the same everywhere. 6.4 The gravitational force does not act until an impetus wears down.

METHOD

Participants

Participants were 522 high schoolers in four public schools in Bangkok, Thailand. Six hundred high schoolers were randomized by using the multistage random sampling method. However, there were 522 participants consenting to participating in this study and completed all of items in a diagnostic test for misconceptions about force and laws of motion. The participants comprised 255 (48.85%) males, and 267 (51.15%) females. There were 176 (33.72%) tenth graders, 176 (33.72%) eleventh graders, and 170 (32.57%) twelfth graders. Numbers of participants according to their sexes and grades are showed in Table 5.

Table 5
Numbers of participants according to their sexes and grades

Grade	Male *n* (%)	Female *n* (%)	Total *n* (%)
Tenth	85 (16.28)	91 (17.43)	176 (33.72)
Eleventh	89 (17.05)	87 (16.67)	176 (33.72)
Twelfth	81 (15.52)	89 (17.05)	170 (32.67)
Total	255 (48.85)	267 (51.15)	522 (100.00)

Materials

Materials used in this study were (1) a diagnostic test for misconceptions about force and laws of motion, and (2) scoring rubrics that were used to score participants' item responses in the diagnostic test. Details of each material were described as follows:

A Diagnostic Test for Misconceptions about Force and Laws of Motion

A diagnostic test for misconceptions about force and laws of motion was a constructed-response test consisting of 18 items. Item responses were scored using scoring rubrics, which contained a three-points scale consisting of 0 for an incorrect response, 1 for a partially correct response, and 2 for a completely correct response. The diagnostic test was used to assess six attributes of misconceptions about force and laws of motion, i.e., (1) resultant force, (2) Newton's first law of motion, (3) Newton's second law of motion, (4) Newton's third law of motion, (5) frictional force, and (6) gravitational force. It was designed in accordance with the CDA. Development procedures of the diagnostic test and its psychometric properties were presented as follows:

Development Procedures of the Diagnostic test. First, we constructed a Q-matrix by considering the relationships among attributes in the cognitive model of force and laws of motion proposed by Wancham et al. (2022). The Q-matrix construction was comprised of three steps, i.e., (1) constructing an incidence matrix, (2) constructing a reachability matrix, and (3) constructing a reduced Q-matrix. Then, four physics experts and three experts in educational measurement and evaluation were asked to review the accuracy and suitability of the Q-matrix construction. After that, we wrote 18 items to diagnose misconceptions about force and laws of motion according to the Q-matrix. These test items were used to validate the Q-matrix with two methods, i.e., think-aloud protocols, and an expert panel. The information gathered from the two methods was used to revise the Q-matrix and test items. The Q-matrix validated by the expert panel and think-aloud protocols are showed in Table 6.

Table 6
The Q-matrix validated by expert panel and think-aloud protocols

Item	Resultant force	First law	Second law	Third law	Frictional force	Gravitational force
1	1	0	0	0	0	0
2	0	1	0	0	0	0
3	1	1	0	0	0	0
4	0	0	1	0	0	0
5	1	1	1	0	0	0
6	0	0	0	1	0	0
7	1	0	0	1	0	0
8	0	1	0	1	0	0
9	1	1	0	1	0	0
10	1	1	1	1	0	0
11	0	0	0	0	1	0
12	1	1	1	0	1	0
13	0	0	0	0	0	1
14	1	1	1	0	0	1
15	0	1	1	1	1	0
16	0	0	1	1	0	1
17	0	1	1	0	1	1
18	0	0	1	1	1	1

Psychometric Properties of the Diagnostic Test. To examine psychometric properties, the diagnostic test was administered to 522 participants within 90 minutes. Participants' responses were analyzed to collect psychometric properties of the diagnostic test. Its psychometric properties were presented as follows:

(1) The majority of test items were high quality (Ma & de la Torre, 2016). Item parameters obtained from the analysis through the use of the sequential bug-G-DINA model comprised (a) the processing functions of category 1, which were 0.87 - 1.00, for participants possessing a reduced attribute profile that contained all 0, and 0.02 - 0.21, for those possessing a reduced attribute profile that contained all 1; and (b) the processing functions of category 2, which were 0.77 - 1.00, for participants possessing a reduced attribute profile that contained all 0, and 0.00 - 0.20, for those possessing a reduced attribute profile that contained all 1.

(2) The diagnostic test contains a high classification consistency index and classification accuracy index (Ravand, 2016) of 0.86 and 0.95, respectively.

(3) The diagnostic test had high concurrent validity (Rodrigues et al., 2019) because diagnostic results from the sequential bug-G-DINA model were highly consistent with the results from think-aloud protocols (Cohen's kappa = 0.84).

(4) The diagnostic test had construct validity because results of a confirmatory factor analysis revealed that the measurement model of misconceptions about force and laws of motion – as shown in Figure 1 – fitted the empirical data ($\chi^2(2, N = 522) = 1.58$, $p = .45$, CFI = 1.00, TLI = 1.00, RMSEA = 0.00, SRMR = 0.01).

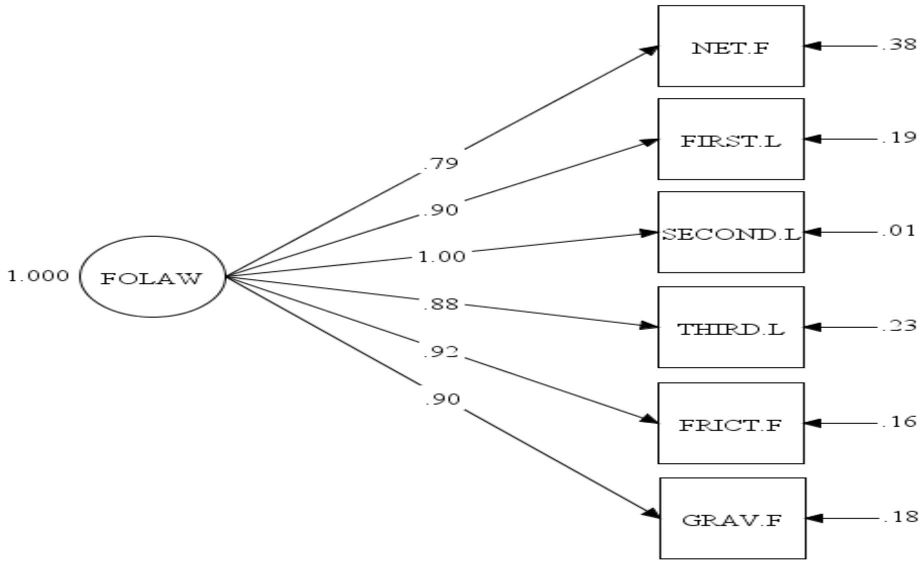

Figure 1
Confirmatory factor analysis results of measurement model of misconceptions about force and laws of motion

Scoring Rubrics

Scoring rubrics were used to rate participants' responses in the diagnostic test for misconceptions about force and laws of motion. The scoring rubrics contained a three-point scale consisting of 0 for an incorrect response, 1 for a partially correct response, and 2 for a completely correct response. These scoring rubrics were reviewed by seven experts in physics. Moreover, scoring rubrics were found to have a high inter-rater reliability (Rodrigues et al., 2019) with Fleiss' kappa coefficients ranging from 0.82 to 0.97.

Data Analysis

We employed the sequential bug-G-DINA model to analyze participants' responses in the diagnostic test for misconceptions about force and laws of motion using the GDINA R package (Ma et al., 2021). The *GDINA* function was used for model estimation. Then, the *modelfit* function was applied to determine the model-data fit, and the *coef* function was used to extract two item parameters of each category of an item, excluding category 0. The two item parameters were (1) the processing functions for participants who possessed a reduced attribute profile that contained all 0 (not having misconceptions in all attributes assessed by a given item) and (2) the processing functions for participants who possessed a reduced attribute profile that contained all 1 (having misconceptions in all attributes assessed by a given item). The item parameters were used to determine the quality of test items. While, the *personparm* function was used to diagnose misconceptions about each attribute of force and laws of motion held by participants. Moreover, we used the model estimation results to further validate the Q-matrix. The *Qval* and *plot* function were employed to create mesa plots of each item that provides information for correcting the Q-matrix so that a complete Q-matrix was obtained. A mesa plot is a line graph that demonstrates the best q-vector (Q-matrix row vector) for each item on the edge of the mesa.

To compare the proportions of participants of different sexes and grades who possessed each attribute of misconceptions about force and laws of motion, a chi-square test was used in the SPSS software and the significance level was determined at 0.05.

FINDINGS

Misconceptions Diagnosis

The status of participants' misconception of each attribute was estimated by the sequential bug-G-DINA model. Their item responses and an unrestricted Q_c-matrix were inputted into data analysis. Due to polytomous scoring of participants' responses, the Q-matrix for dichotomous responses analysis – as shown in Table 6 – was converted into the unrestricted Q_c-matrix. This matrix contained two categories (i.e., category 1 and 2, excluding category 0) with each item in the rows. All attributes measured by an item were measured in each item category indicated in Table 6. Before interpreting the status of participants' misconceptions, we assessed the model-data fit by determining the standardized root mean squared residual (SRMSR) and validated the unrestricted Q_c-matrix by considering the mesa plots. The sequential bug-G-DINA model fitted well with participants' empirical responses (SRMSR = 0.04) because the SRMSR was below 0.05 (Maydeu-Olivares & Joe, 2014 as cited in Ma, 2020). In order to consider a mesa plot of category 1 and 2 for each item, we only changed the q-vector of category 2 of item 10 from 111100 to 011000. This revised Q-matrix was reviewed by seven experts in physics.

The diagnosis of misconceptions about force and laws of motion found that the number of participants who possessed misconceptions were higher than the number of participants who possessed correct concepts in all six attributes. The attributes that saw the highest percentage of participants possessing misconceptions were Newton's first law of motion (84.48%), frictional force (77.20%), gravitational force (74.90%), Newton's second law of motion (72.99%), Newton's third law of motion (64.75%), and resultant force (62.26%), in that order, as shown in Table 7.

Table 7
Numbers of participants who possessed misconceptions and correct concepts about force and laws of motion

Attribute	Correctness *n* (%)	Misconception *n* (%)
Resultant force	197 (37.74)	325 (62.26)
Newton’s first law of motion	81 (15.52)	441 (84.48)
Newton’s second law of motion	141 (27.01)	381 (72.99)
Newton’s third law of motion	184 (35.25)	338 (64.75)
Frictional force	119 (22.80)	403 (77.20)
Gravitational force	131 (25.10)	391 (74.90)

Additionally, we determined participants’ attribute profiles that indicated unique categories of misconception status for each attribute. For attribute profiles, there were six binary digits (i.e., 1 indicating having misconceptions and 0 indicating having correct concepts) that were sorted in order of all six attributes. There were 64 (2^6) possible attribute profiles because the diagnostic test for misconceptions about force and laws of motion measured six attributes. However, 40 empirical attribute profiles were found in participants. The numbers of those in each attribute profile ranged from 1 (0.19%) to 205 (39.37%), as shown in Figure 2. The majority of them (39.37%) were put in profile 111111. That is, they possessed misconceptions about force and laws of motion in all six attributes.

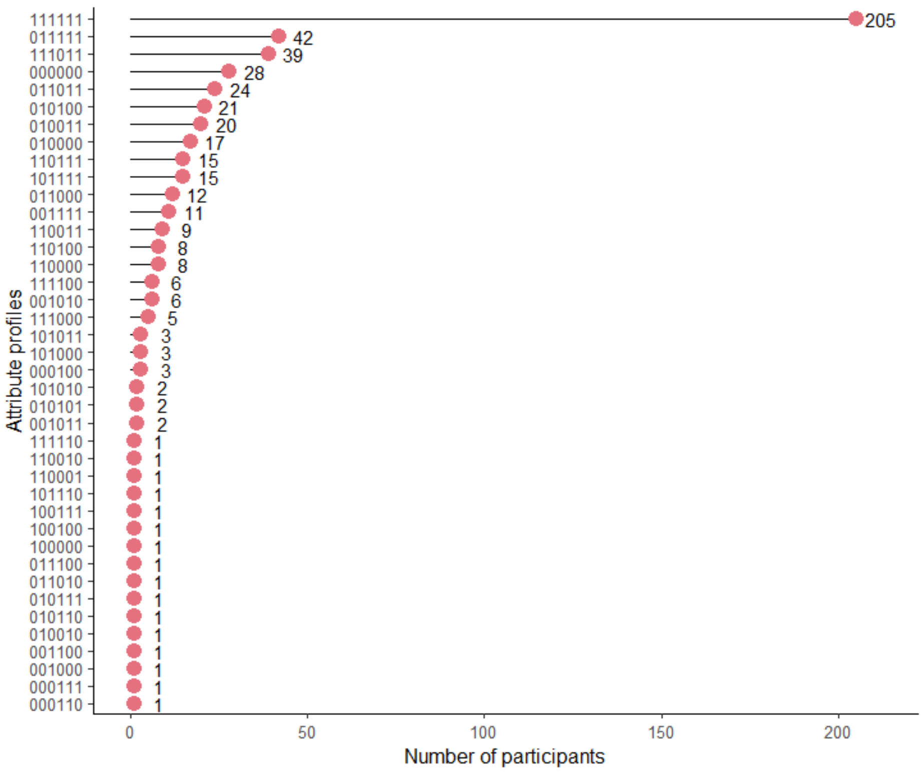

Figure 2
Numbers of participants in each attribute profile

Notes. There were six binary digits in each attribute profile that were sorted in order of all six attributes, which were (1) resultant force, (2) Newton's first law of motion, (3) Newton's second law of motion, (4) Newton's third law of motion, (5) frictional force, and (6) gravitational force, respectively.

Proportional Differences Comparison

The results of comparing the proportions of participants of different sexes who possessed misconceptions about each attribute of force and laws of motion demonstrated that there was only a significant difference in the proportion of male and female students possessing misconceptions about resultant force, at the .05 level of significance, $\chi^2(1, N = 522) = 10.30$, $p = .001$. In other words, the proportion of male students with misconceptions was statistically lower than that of their female counterparts, as shown in Figure 3. For five other attributes, the proportional difference of students of different sexes with misconceptions were not statistically significant, at the .05 level of significance. The results for each attribute were as follows:(1) Newton's first law of motion [$\chi^2(1, N = 522) = 0.39$, $p = .53$],)2(Newton's second law of motion [$\chi^2(1, N =$

522) = 0.18, p = .68],)3(Newton's third law of motion [$\chi^2(1, N = 522) = 1.26, p = .26$],)4(frictional force [$\chi^2(1, N = 522) = 0.03, p = .86$], and)5(gravitational force [$\chi^2(1, N = 522) = 0.00, p = 1.00$].

Figure 3
Numbers of participants who possessed misconceptions and correct concepts about force and laws of motion according to their sexes

The results for comparing the proportional difference among participants of different grades who possessed misconceptions about each attribute of force and laws of motion revealed that there were statistically significant differences in the proportions of students of different grades who possessed misconceptions about resultant force [$\chi^2(2, N = 522) = 8.28, p = .02$] and Newton's second law of motion [$\chi^2(2, N = 522) = 9.13, p = .01$], at the .05 level of significance. That is, the number of students with misconceptions about resultant force was the lowest among the twelfth graders, followed by the eleventh graders and the tenth graders, respectively. This was consistent with another result that found the number of students with misconceptions about Newton's second law of motion was the lowest among the twelfth graders, while the numbers of students with misconceptions about this attribute was proportionately similar among tenth and eleventh graders, as shown in Figure 4. In addition, the proportional difference of students possessing misconceptions about four other attributes was not statistically different, at the .05 level of significance. The results for the four attributes were as follows: (1) Newton's first law of motion [$\chi^2(2, N = 522) = 0.03, p = .98$],)2(Newton's third law of motion [$\chi^2(2, N = 522) = 4.86, p = .09$],)3(frictional force [$\chi^2(2, N = 522) = 4.38, p = .11$], and)4(gravitational force [$\chi^2(2, N = 522) = 5.02, p = .08$].

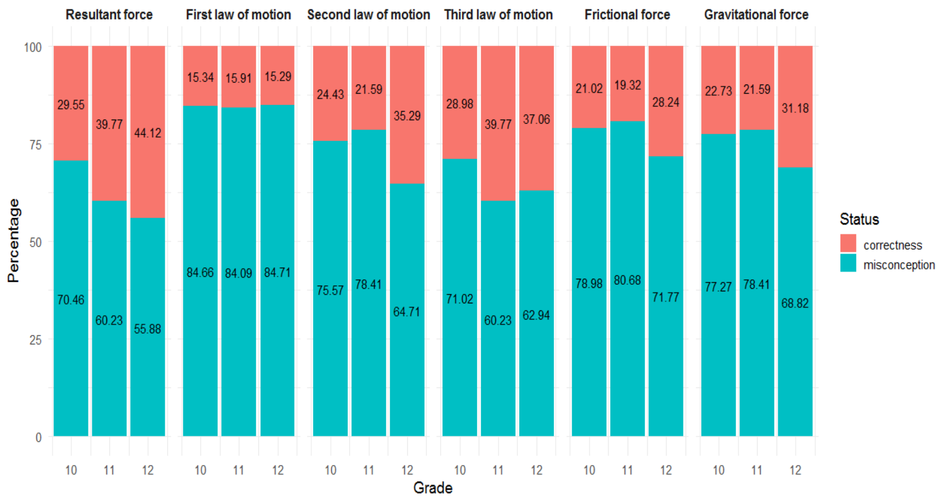

Figure 4
Numbers of participants who possessed misconceptions and correct concepts about force and laws of motion according to their grades

DISCUSSION

Discussion on Misconceptions Diagnosis

The results of the diagnosis of misconceptions about force and laws of motion suggested that the number of participants who possessed misconceptions were higher than the number of those who possessed correct concepts for all six attributes. The percentage of those who possessed misconceptions about Newton's first law of motion was the highest. For other five attributes, the percentages of having misconceptions was similar. These findings were in accordance with previous studies that examined students' misconceptions about force and laws of motion, e.g., Azman et al. (2013), Bouzid et al. (2022), and Suprapto et al. (2016). That is, students around the world show an analogous pattern of these misconceptions. Furthermore, students' social and cultural backgrounds do not influence these misconceptions. In other words, misconceptions about force and laws of motion are universal in nature (Al-Rsa'i et al., 2020; Bani-Salameh et al., 2017).

The majority of participants that had misconceptions about force and laws of motion in all six attributes could be attributed to their recognition of physics as uninteresting, abstract and difficult. As a result, they lose interest in learning physics (Syafril et al., 2021). For another explanation, they learned physics by focus on memorizing formulas without taking an effort to comprehend the concepts of force and laws of motion (Narjaikaew, 2013).

Misconceptions about Newton's first law of motion are linked to the impetus idea, which contradicts Newton's first law of motion. The impetus force is students' imaginative force that leads them to believe that an impetus is an inanimate motive power or an intrinsic force that comes from an applied force and keeps objects moving. An impetus can be gained or lost in a variety of ways, according to each student's belief. The impetus idea stipulates that a resultant force is required to keep an object moving at a constant velocity. In fact, the object has a zero resultant force acting on it (Suprapto et al., 2016). Participants possessing misconceptions about Newton's first law of motion more than other attributes could be attributed to their real-life experience of seeing most of the objects moving with an applied force acting on them or with fuel as they move. As a result, they misunderstood that every object contained an acting force in the form of impetus that acts like fuel that keeps the object moving. (Azman et al., 2013; Bouzid et al., 2022). Moreover, Mackay (2019) found that misconceptions about Newton's first law of motion were difficult to correct. Most of participants, thus, retained these misconceptions throughout the course of learning physics.

Discussion on Proportional Differences Comparison

According to the findings, the number of male students with misconceptions about resultant force was statistically lower than that of their female counterparts in a significant way. This is likely because male students had experiences with force and were more interested in physics phenomena than their female counterparts (Azman et al., 2013). For five other attributes, the proportional difference between male and female students was not statistically significant. That could be because of the universal nature of misconceptions about force and laws of motion, which is not based on socio-cultural backgrounds or students' sex (Bani-Salameh et al., 2017). Male and female students, thus, show a similar pattern of misconceptions.

According to the finding, there were only a significant difference in the proportions of students of different grades with misconceptions about resultant force and Newton's second law of motion. The number of the twelfth graders with misconceptions was lower than that of the eleventh and tenth graders. This is likely because the concepts of resultant force and Newton's second law of motion are important concepts that are applied to a lot of physics lessons. The twelfth graders have more experiences of applying the two concepts in solving physics problems than the eleventh and tenth graders. As a result, they had a better understanding of these concepts and recognized their misconceptions that led them to correct these misconceptions themselves (Suprapto et al., 2016). For four other attributes, the proportional differences were not statistically significant. That is likely because misconceptions about force and laws of motion are difficult to be corrected. Consequently, these misconceptions are retained even after these concepts have been taught to them. (Bani-Salameh, 2016).

In this study, we diagnosed students' attribute of misconceptions about force and laws of motion by using the sequential bug-G-DINA model, a cognitive diagnostic model. Consequently, diagnostic results were accurate and used to identify whether a student has misconceptions or not. Besides, we employed these diagnostic results to compare proportional differences. It is different from previous studies that used total scores to determine and to compare students' misconceptions. However, the results of this study supported previous studies that high schoolers of different sexes and grades had the same patterns of misconceptions about force and laws of motion.

CONCLUSIONS

This study aimed to diagnose high schoolers' misconceptions about force and laws of motion using the CDA and compare the proportional differences of students of different sexes and grades who possessed misconceptions about each attribute of force and laws of motion. The findings found that the percentage of participants who possessed misconceptions was high for all six attributes. There was only a significant difference in the proportions of male and female students possessing misconceptions about resultant force. In addition, there were only significant differences in the proportions of students of different grades possessing misconceptions about resultant force and Newton's second law of motion. The findings indicated that male and female high schoolers had similar misconceptions. Moreover, participants still retained the misconceptions even after the concepts have been taught to them. This demonstrates that the participants from each grade showed similar misconceptions, as reflected by the high percentage of misconception exhibition.

Students who have misconceptions about force and laws of motion will be unsuccessful in learning mechanics and physics because they cannot apply the concept of force and laws of motion to mechanics or other complex physics concepts (Aini et al., 2021; Gurel et al., 2015). Teachers should give importance to diagnosing misconceptions about force and laws of motion and correcting students' misconceptions to help them successfully learn physics. The research findings suggested teachers should develop remedial programs to correct their high schoolers' misconceptions about force and laws of motion for all six attributes, i.e., (1) resultant force, (2) Newton's first law of motion, (3) Newton's second law of motion, (4) Newton's third law of motion, (5) frictional force, and (6) gravitational force. Additionally, female high schoolers need an assistance on correcting misconceptions about resultant force more than their male counterparts. While, tenth and eleventh graders require reinforcement to eradicate misconceptions about resultant force and Newton's second law of motion more than twelfth graders.

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