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Misconceptions of High School Students on Motion and ForceUsing the Force Concept Inventory (FCI)

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Abstract: This research aims to identify high school students' misconceptions regarding motion and force using the Force Concept Inventory (FCI) instrument. This study used a quantitative method with respondents of 108 students in class XI science. Misconception data was obtained using FCI in the form of multiple-choice questions. There are 30 questions with five options. The results showed that a total of 46 out of 108 students (19.44%) answered 8 to 11 questions correctly, 41 students (37.96%) answered 5 to 7 questions correctly and the other 21 students (42.59%) only answered 2 to4 questions correctly. The conclusion is students had misconceptions about the concepts of motion and force, especially on topics such as kinematics, Newton's laws, the principle of superposition, and kinds of force. This research impliesthe importance of understanding students' misconceptions in developing physics curricula and learning strategies in high schools. It is hoped that the research results can provide information to teachers about students' conceptual understanding so that appropriate learning strategies can be developed to correct students' misconceptions in learning.

Keywords: Conceptual Understanding; Force Concept Inventory (FCI); High School Student; Misconceptions; Motion and Force

Introduction

Physics is a scientific discipline that studies the universe, motion, energy, and matter. Physics has an important role in the development of modern science and technology. Given the relevance of physics to society, the learning process in schools must be correctly implemented, which includes students' knowledge and application of physics ideas (Hunaidah et al., 2022). Understanding of physics requires thinking and reasoning to solve problems (Maknun, 2020). When learning physics, students must grasp the occurrence of a concept, how to obtain it, and the relationship between concepts (Purwanto & Winarti, 2020). However, low conceptual understanding of physics and many misconceptions often become obstacles for students in the learning process (Azizah et al., 2015; Puspitasari et al., 2021). Physics is one of the scientific disciplines that frequently leads to a lot of misconceptions among students (Atika et al., 2023; Soeharto et al., 2019). Misconceptions are common, especially among students who are lacking in analytical abilities (Mahardika et al., 2020). Misconceptions usually emerge in students when connecting an idea comprised of many basic principles that require a deeper understanding (Meiliyadi et al., 2023). Misconception is one of the difficulties to achieving physics learning, and it must be remedied immediately so that misconceptions are not retained in following knowledge (Halim et al., 2024) Misconceptions can hinder students' understanding and complicate teaching efforts (Syuhendri, 2019).

Students learn about their natural surroundings through learning at school and personal experiences (Jauhariyah et al., 2018). Students' perceptions are theoretically shaped by their interactions with other people and the surrounding environment (Osman &

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Sukor, 2013). As a result, students' perceptions may not be following scientific concepts. Students' understanding of concepts that are different from scientific concepts is due to interpretations of daily personal life, which provide an understanding of the universe and its contents (Syuhendri, 2021). Differences in concepts can also occur because the concepts that students get at the beginning before entering school and after school are different (Syuhendri, 2017). This is because they already have an idea of the universe before receiving lessons at school (Syuhendri, 2022). The term states thatsomething is understood differently from the actual scientific concept is also known as a misconception (Shidik & Tae, 2022; Syuhendri, 2019; Yuliati, 2017). Misconception is a mistaken understanding or belief about a particular subject (Dewi et al., 2023) and is used as a habit (Afriwardani et al., 2023). Misconceptions in physics are inaccurate definitions, misuse, misclassification of examples, and false hierarchical relationships between concepts (Maknun & Marwiah, 2022).

One of the physics misconceptions that occurs among students is misunderstanding about Newtonian mechanics (Syuhendri, 2017), namely weights, normal forces and Newton third law (Mongan et al., 2020), gravity (Syuhendri, 2019), and acceleration (Setiono et al., 2021). Misconceptions tend to be difficult to change andtraditional learning does not provide satisfactory results in overcoming them (Rafika & Syuhendri, 2021). There are several theories to overcome misconceptions, one of which is the theory of conceptual change put forward by Posner et al. (1982). Conceptual change theory is a theory that explains how someone can change their perspective or beliefs from wrong to right in the context of understanding concepts. Therefore, the first step that is needed before carrying out learning to overcome misconceptions is to identify and analyze the misconceptions or wrong understanding experienced by students (Mursadam et al., 2017; Utami & Khotimah, 2023).

There are several ways to analyze students' misconceptions and differentiate between incorrect understanding and correct understanding. One way is to use the FCI (Force Concept Inventory) instrument developed by Hestenes, Halloun, Wells, and Swackhamer in 1992 (Hestenes et al., 1992). This instrument is designed to measure understanding of the concept of style in students from various levels of education, from entry-level to college level, which has been validated and has been widely used.

Previous research on misconceptions was conducted by Handhika et al. (2017) who used FCI to identify misconceptions among high school students in the Madiun area. Research by Bani-Salameh (2017) which uses FCI to diagnose first-year student misconceptions. Syuhendri (2022) has also researched teaching for conceptual change on Newton's First Law, which uses FCI to analyze the results of changes in physics education students' conceptions. However, research analyzing the misconceptions of high school students using FCI in the Palembang area has never been conducted. Therefore, the novelty of this research is analyzing the misconceptions of high school students using FCI in the Palembang area on the topic of motion and force. It is important to analyze misconceptions as early as possible so that changes in conceptions can occur in the right direction for students, especially in the high schools in Palembang, so the teachers can improve the learning strategies given to students. This is because a learning strategy that ignores misconceptions might lead to low achievement among students (Gumay, 2021). Therefore, this research aims to identify the misconceptions that students at one of the high schools in Palembang, Indonesia have on the topic of motion and force using the Force Concept Inventory instrument. This research is basic research to develop various strategies for overcoming misconceptions in learning based onthe proposed theory of conceptual change.

Method

The method used in this research is a quantitative method. This research was conducted at a state high school in Palembang, Indonesia. Respondents consisted of 108 students in class XI Science. The instrument used was the Force Concept Inventory (Hestenes et al., 1992) which is a multiple-choice test on motion and force material. The FCI consists of 30 question items with five options. One option is a correct concept while the other four options are misunderstandings in the topic discussed. Some of the concepts contained in the FCI instrument include motion kinematics, Newton's first law, Newton's second law, Newton's third law, the principle of superposition, and kinds of force. Table 1 shows each item on the FCI and related concepts.

Table 1. Concepts in FCI and Numbers of Questions

Topic	Question number
Kinematics	9, 14,19, 20, 21, 22, 27
Newton's first law	6, 7, 8, 10, 17, 23, 24, 27
Newton's second law	8, 9, 21, 22, 26
Newton's third law	4, 15, 16, 25, 28
Superposition principle	11, 17
Kinds of force	1, 2, 3, 5, 11, 12, 13, 14, 17, 18, 29, 30

Student answer data is grouped based on the concept investigated using FCI. Researchers then analyzed students' answers for each item on each concept. Then the answer scores are tabulated based on the concepts in the FCI and the frequency percentage of each category of student answers is calculated to determine the level of student understanding using the equation

$$P=(f/N)\times 100\% \quad (1)$$

Where:
P = Final Value
f = Score Acquisition
N = Maximum score
(Rafika & Syuhendri, 2021)

Result and Discussion

Results were obtained from students' answers to the multiple-choice test on the Force Concept Inventory (FCI) instrument. Data analysis was carried out by finding the average percentage of students' concept understanding using the FCI instrument. Based on data analysis, the average percentage of students' conceptual understanding for each question is shown in Figure 1. Figure 1 shows that students answered the most correctly on item number 6 with a percentage of 51.85% and the least correct on item number 28 with a percentage of 7.41%

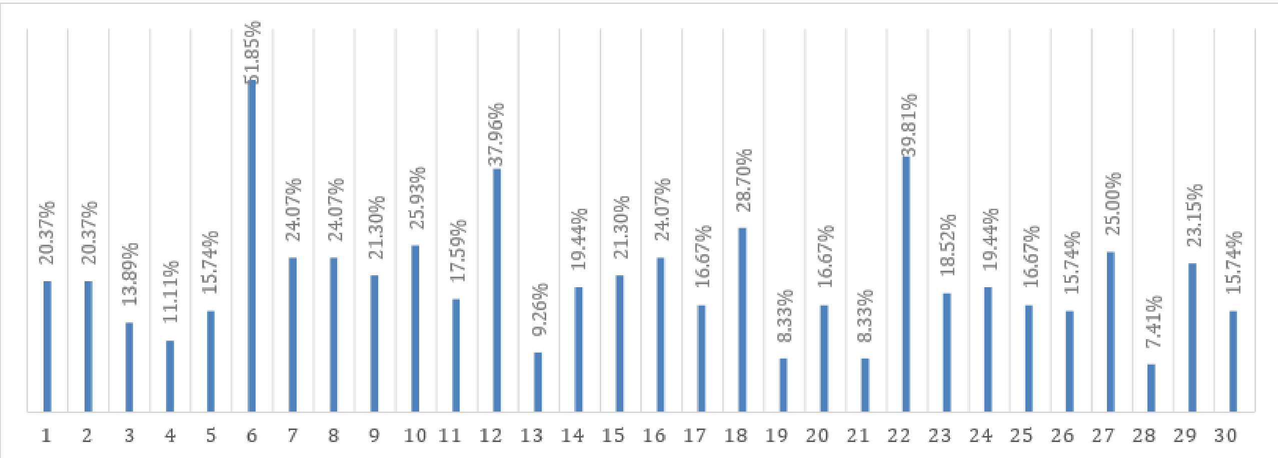


Figure 1. Per centage of correct answers for each FCI question

With the percentage distribution of correct answers from 108 students who took the test, 46 students (19.44%) answered 8 to 11 questions correctly, 41 students (37.96%) answered 5-7 questions correctly and 21 students (42.59%) only answered 2 to 4 questions correctly as shown in Figure 2. This shows the magnitude of misconceptions about the conceptsof motion and force

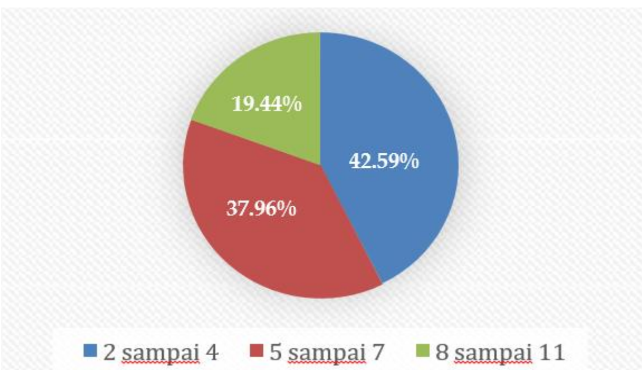


Figure 2. Distribution of answer results from 108 students

Based on the data in Table 2, several misconceptions that occurred among students were also found, including:

In free-fall motion, what affects the fall time and fall distance is not only the acceleration due to gravity but also the weight of the object. A heavier object's weight makes the object fall faster and the acceleration due to gravity increases as it approaches the ground surface and decreases as it moves away from the ground surface. These results are in accordance with previous research by Syuhendri (2019) and Poutot & Blandin (2015). In fact, free-fall is only influenced by gravitational acceleration and the value of gravitational acceleration does not increase or decrease (Toda et al., 2020). Examples of questions about this misconceptioncan be seen in Figure 3.

1. Dua buah bola logam berukuran sama tapi berbeda berat, bola pertama beratnya dua kali lipat berat bola kedua. Bola tersebut dijatuhkan serentak dari atas sebuah gedung bertingkat. Waktu yang dibutuhkan kedua bola untuk sampai ke tanah adalah:
   A. bola berat membutuhkan waktu kurang lebih setengah dari waktu yang dibutuhkan bola ringan.
   B. bola ringan membutuhkan waktu kurang lebih setengah dari waktu yang dibutuhkan bola berat.
   C. Kurang lebih sama untuk kedua bola.
   D. bola berat membutuhkan waktu lebih sedikit, namun tidak harus setengah dari waktu yang dibutuhkan bola ringan.
   E. bola ringan membutuhkan waktu lebih sedikit, namun tidak harus setengah dari waktu yang dibutuhkan bola berat.

2. Dua buah bola logam yang sama dengan soal nomor 1 menggelinding di atas meja datar dengan kelajuan sama dan kemudian jatuh ke lantai. Pada situasi ini, tempat jatuh kedua bola di lantai diukur mendatar dari kaki meja adalah:
   A. kedua bola jatuh pada jarak yang sama.
   B. bola berat jatuh pada jarak kurang lebih setengah jarak jatuhnya bola ringan.
   C. bola ringan jatuh pada jarak kurang lebih setengah jarak jatuhnya bola berat.
   D. bola berat jatuh lebih dekat dibandingkan bola ringan, tetapi jaraknya tidak harus setengahnya.
   E. bola ringan jatuh lebih dekat dibandingkan bola berat, tetapi jaraknya tidak harus setengahnya.

3. Sebuah batu yang jatuh dari atas sebuah gedung bertingkat ke permukaan bumi
   A. mencapai kelajuan maksimumnya sesaat setelah dilepaskan dan kemudian bergerak dengan kelajuan konstan.
   B. semakin cepat sepanjang perjalanan jatuhnya karena adanya tarikan gravitasi yang semakin besar seiring dengan semakin dekatnya batu ke bumi.
   C. semakin cepat karena adanya gaya gravitasi yang hampir konstan yang selalu bekerja padanya.
   D. jatuh karena kecenderungan alami setiap benda untuk diam di permukaan bumi.
   E. jatuh karena pengaruh gabungan gaya gravitasi dan gaya oleh tekanan udara yang mendorong batu ke bawah.

Figure 3. Questions about free-fall motion

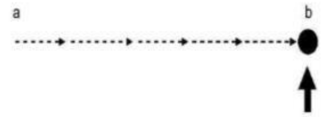
Larger objects exert a greater total force on smaller objects when they collide. Similar things were also found in research conducted by Amaliah & Purwaningsih (2021), Syuhendri (2019) and Fauziah & Darvina (2019). Even though in the concept of Newton's third law. Two objects interacting with each other will exert an equal force on each other (Zhou et al., 2015). An example of a question related to this misconception is shown in Figure 4.

4. Sebuah truk besar bertabrakan beradu kepala dengan sebuah sedan kecil. Pada saat tabrakan,
   A. truk mengerjakan total gaya yang lebih besar terhadap sedan dibandingkan sedan mengerjakan gaya terhadap truk.
   B. sedan mengerjakan total gaya yang lebih besar terhadap truk dibandingkan truk mengerjakan gaya terhadap sedan.
   C. tidak ada gaya yang dikerjakan oleh truk terhadap sedan dan begitu sebaliknya; sedan jadi hancur hanya karena ia menghalangi jalan truk.
   D. truk mengerjakan gaya terhadap sedan tetapi sedan tidak mengerjakan gaya terhadap truk.
   E. truk mengerjakan gaya terhadap sedan sama besar dengan gaya yang dikerjakan sedan terhadap truk.

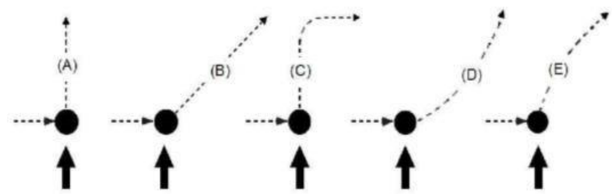
Figure 4. Questions about Newton's third law

The direction of the velocity vector is influenced by the last force applied and vector addition is considered the same as ordinary arithmetic addition. This research is in accordance with previous research conducted by Syuhendri(2017). In fact, thedirection of the velocity vector is influenced by the force exerted on the horizontal and vertical axes (Gumilar, 2016). So, the summation is also influenced by the horizontal and vertical components. Examples of questions about this misconception can be seen in Figure 5.

Gambar di bawah ini memperlihatkan sekeping cakram pada permainan hoki yang bergerak dengan kelajuan konstan $\mathbf{v_0}$ dari titik "**a**" ke titik "**b**" membentuk garis lurus di atas bidang datar tanpa gesekan. Gaya oleh udara juga diabaikan. Anda sedang melihatnya dari atas. Ketika cakram sampai di titik "**b**", cakram tersebut dipukul mendatar dalam arah yang diperlihatkan oleh anak panah tebal. Seandainya cakram dalam keadaan diam di titik "**b**", maka pukulan yang diberikan jelas akan menyebabkannya bergerak mendatar searah pukulan dengan kelajuan $\mathbf{v_p}$.



8. Lintasan manakah di bawah ini yang paling tepat diikuti cakram setelah cakram itu dipukul?



9. Kelajuan cakram sesaat setelah menerima pukulan adalah.
   A. sama dengan kelajuan "$\mathbf{v_0}$" yang dimilikinya sebelum mendapat pukulan.
   B. sama dengan kelajuan "$\mathbf{v_p}$" yang diperoleh dari "pukulan" dan tidak ada hubungannya dengan kelajuan "$\mathbf{v_0}$".
   C. sama dengan penjumlahan aritmatik (hitung) kelajuan "$\mathbf{v_0}$" dan "$\mathbf{v_p}$".
   D. lebih kecil dari kelajuan "$\mathbf{v_0}$" atau "$\mathbf{v_p}$".
   E. lebih besar dari kelajuan "$\mathbf{v_0}$" atau "$\mathbf{v_p}$" tetapi lebih kecil dari penjumlahan aritmatik (hitung) kedua kelajuan tersebut.

Figure 5. Questions about direction of velocity vector

In circular motion, the object's trajectory is not perpendicular to its centripetal acceleration. In fact, the direction of the trajectory in circular motion is influenced by the centripetal acceleration towards the center of the circle sand the linear speed which is perpendicular to the centripetal acceleration (Arzak et al., 2021). These results are in line with research conducted by Fauziah & Darvina (2019) and Sari et al. (2018). Examples of questions regarding this misconception can be seen in Figure 6.

7. Sebuah bola logam diikat dengan seutas tali dan diputar mendatar membentuk lintasan melingkar horizontal seperti gambar di samping. Di titik **P** seperti yang diperlihatkan gambar, tiba-tiba tali putus dekat bola. Jika kejadian ini dilihat dari atas, lintasan manakah yang paling tepat diikuti bola setelah tali putus?

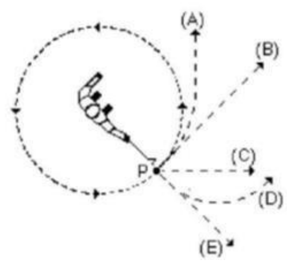


Figure 6. Questions about circular motion

When a moving object is suddenly stopped, the source of its motion will continue to move for a while, then slow down and stop or stop immediately. The results of this research are similar to research conducted by Syuhendri (2018) and Fauziah & Darvina (2019). In fact, the correct concept is that objects will slow down until they stop. This is caused by the concept of Newton's 1st law where objects will try to maintain their position (Taufiq & Kaniawati, 2023). An example of a question related to this misconception is shown in

Figure 7.

27. Jika wanita pada soal 25 di atas tiba-tiba berhenti mengerjakan gaya mendatar terhadap kotak, maka kotak akan:
A. langsung berhenti.
B. terus bergerak dengan kelajuan konstan untuk sementara waktu dan kemudian melambat sampai berhenti.
C. langsung melambat sampai berhenti.
D. terus bergerak dengan kelajuan konstan.
E. memperbesar kelajuannya untuk sementara waktu dan kemudian mulai melambat sampai berhenti.

Figure 7. Question about Newton's 1st law

The trajectory caused by motion in the horizontal and vertical directions takes the form of one of the larger directions of motion. The results of this research are in accordance with research conducted by Fauziah & Darvina (2019). Even though the direction of the trajectory formed is a parabolic trajectory. An example of a question related to this misconception is shown in Figure 8.

12. Seseorang menembakkan meriam dari atas tebing seperti diperlihatkan pada gambar di bawah ini. Lintasan manakah yang paling tepat diikuti peluru meriam setelah ditembakkan?

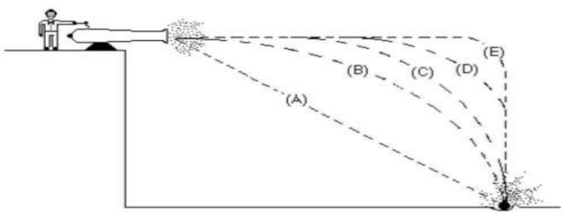
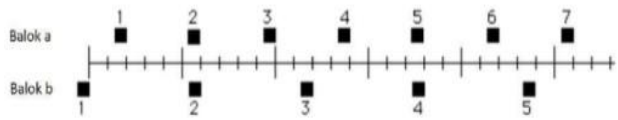


Figure 8. Question about parabolic trajectory

The speed in uniform straight motion increases and the acceleration becomes greater. However, in uniform straight motion the speed is constant and the acceleration is zero (Prasastono & Holili, 2023). These results are in accordance with the results of previous research by Fauziah & Darvina (2019). An example of a question related to this misconception is shown in Figure 9.

20. Posisi dua buah balok untuk selang waktu 0,20 detik secara berurutan digambarkan oleh kotak-kotak bernomor pada gambar di bawah. Kedua balok sedang bergerak ke kanan.



Hubungan percepatan kedua balok adalah:
A. Percepatan balok "**a**" lebih besar dari percepatan balok "**b**".
B. Percepatan balok "**a**" sama dengan percepatan balok "**b**". Kedua percepatan, baik percepatan "**a**" maupun "**b**" lebih besar dari nol.
C. Percepatan balok "**b**" lebih besar dari percepatan balok "**a**".
D. Percepatan balok "**a**" sama dengan percepatan balok "**b**". Kedua percepatan, baik percepatan "**a**" maupun "**b**" sama dengan nol.
E. Tidak cukup informasi yang diberikan untuk menjawab soal.

Figure 9. Question about acceleration

Table 2. Analysis of Misconceptions on Motion and Force Material per FCI Question Item

Question number	Topic	Correct answer	Wrong answer	Dominant misconceptions
1	Kinds of force, kinematics	C (20.37%)	A (29.63%) B (22.22%) D (20.37%) E (7.41%)	Heavy balls fall faster thanlighter balls
2	Kinds of force, kinematics	A (20.37%)	D (29.63%) B (24.07%) C (17.59%) E (8.33%)	The weight of the ballaffects the distance the object falls
3	Kinds of force, kinematics	C (13.89%)	B (32.41 %) E (25.00 %) A (23.15%) D (5.56%)	The acceleration due to gravity is greater the closerto the earth's surface
4	Newton's third law	E (11.11%)	A (37.04%) C (21.30%) D (16.67%) B (13.89%)	Larger objects exert a greater total force on smaller objects when they collide
5	Kinds of force, kinematics	B (15.74%)	C (36.11%) A (21.30%) E (18.52%) D (8.33%)	Circular motion is influenced by forces in the direction of the ball's movement
6	Newton's first law	B (51.85%)	A (22.22%) C (10.19%) D (10.19%) E (5.56%)	-

Question number	Topic	Correct answer	Wrong answer	Dominant misconceptions
7	Newton's first law	B (24.07%)	A (27.78%) D (17.59%) C (16.67%) E (13.89%)	The direction of the object's speed is in the same direction as the radius of the circle
8	Newton's first law andsecond law, kinematics	B (24.07%)	A (27.78%) C (16.67%) D (17.59%) E (12.04%)	The direction of motion of the object is determined bythe final force vector
9	Kinematics	E (21.30%)	B (25.93%) A (23.15%) C (19.44%) D (10.19%)	The addition of vector velocities is the same as ordinary addition
10	Newton's first law, kinematics	A (25.93%)	D (26.85%) B (23.15%) E (13.89%) C (10.19%)	Speed in uniform straightmotion increases
11	Principle of superposition, kinds offorce	D (17.59%)	B (30.56%) C (29.63%) E (12.96%) A (9.26%)	The horizontal force in the plane of the disc is the mainforce
12	Kinds of force	B (37.96%)	A (34.26%) C (13.89%) E (7.41%) D (6.48%)	-
13	Kinds of force	D (9.26%)	A (32.41%) B (33.33%) C (16.67%) E (2.78%)	The gravitational force decreases as the ball heads upwards and increases as itapproaches the earth's surface
14	Kinematics, kinds of force	D (19.44%)	A (37.04%) B (31.48%) C (19.44%) E (2.78%)	The falling motion is parabolic but behind the moving plane
15	Newton's Third Law	A (21.30%)	B (35.19%) C (17.59%) D (14.81%) E (11.11%)	Larger objects have agreater total force on smaller objects
16	Newton's Third Law	A (24.07%)	B (26.85%) C (20.37%) D (18.52%) E (10.19%)	Larger objects have agreater total force on smaller objects
17	Newton's First Law, Principle of Superposition	B (16.67%)	E (33.33%) A (25.93%) D (15.74%) C (8.33%)	The elevator rises because the cable continues to roll, not because of an upward force
18	Kinds of Force	B (28.70%)	C (23.15%) A (17.59%) D (17.59%) E (12.96%)	-
19	Kinematics	E (8.33%)	D (33.33%) B (26.85%) A (20.37%) C (11.11%)	The same location is considered the same speed
20	Kinematics	D (16.67%)	A (37.04%) C (20.37%) B (14.81%) E (11.11%)	The acceleration of block Ais greater than block B

Question number	Topic	Correct answer	Wrong answer	Dominant misconceptions
21	Kinematics	E (8.33%)	A (34.26%) B (32.41%) C (14.81%) D (10.19%)	The trajectory formed is nota parabolic trajectory
22	Kinematics	B (39.81%)	A (23.15%) C (19.44%) B (11.11%) D (6.48%)	-
23	Newton's First Law	B (18.52%)	A (29.63%) D 24.07%) C (23.15%) E (4.63%)	The object's motion changesafter the engine is turned off
24	Newton's First Law	A (19.44%)	C (25.00%) D (23.15%) B (22.22%) E (10.19%)	The speed of the rocket afterthe engine is turned off is changed
25	Newton's Third Law	C (16.67%)	E (27.78%) A (25.00%) B (19.44%) D (11.11%)	The constant force is equal to the weight of the object. Constant force is greater than the total force opposing the motion of the object
26	Newton's Second Law	E (15.74%)	A (36.11%) C (18.52%) B (15.74%) D (13.89%)	The speed of the box will always be twice the initial speed of the box if the force is twice as constant
27	Kinematics, Newton's First Law	C (25.00%)	B (30.56%) A (25.00%) E (14.81%) D (4.63%)	When you suddenly stop, objects will continue to move for a while, then slow down and stop
28	Newton's Third Law	E (7.41%)	B (33.33%) D (21.30%) A (20.37%) C (17.59%)	The larger student exerts a greater force on the smallerstudent
29	Kinds of Force	B (23.15%)	A (29.63%) C (14.81%) D (6.48%) E (25.93%)	Because an object is stationary, the only force that acts is gravitational force or there is no force that acts
30	Kinds of Force	C (15.74%)	A (24.07%) D (24.07%) B (22.22%) E (13.89%)	The only force acting on thetennis ball before it hits theground is gravity

Based on the results obtained, this research shows that students experience serious misconceptions about the concepts of motion and force. Ultimately, this research is expected to provide information about students' conceptual understanding on the topic of motion and force so that teachers can identify their students' understanding of important concepts in the subjects at the beginning of learning and choose appropriate learning strategies to improve students' understanding of concepts and correcting their misconceptions in learning

Conclusion

Based on data analysis and discussion, a total of 46 out of 108 students (19.44%) answered 8 to 11 questions correctly, 41 students (37.96%) answered 5 to 7 questions correctly and the other 21 students (42.59%) only answered 2 to4 questions correctly. It can be concluded that students had serious misconceptions about the concepts of motion and force, especially on topics such as kinematics, Newton's laws, the principle of superposition, and kinds of force. Students' misconceptions can be caused by interpretations of everyday life, experiences before entering school, and traditional learning that is not effective in overcoming misconceptions. Therefore, understanding students' misconceptions about motion and force is an important thing to pay attention to in developing physics curricula and learning strategies in high schools. It is hoped that the results of this research can provide information to teachers about students' conceptual understanding so that appropriate learning strategies can be developed to correct students' misconceptions in learning.

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Conflicts of Interest

The authors declare no conflicts of interest

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