Determining the errors made by prospective science teachers when drawing free-body diagrams

Filiz KOPARAN – Yunus Emre Middle School 0000-0002-6332-4219
Esin ŞAHİN – Çanakkale Onsekiz Mart University 0000-0001-6506-1507

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Correspondencia a través de **ORCID**: Esin ŞAHİN **0000-0001-6506-1507**

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Abstract: This research aims to identify errors prospective science teachers make when drawing free-body diagrams (FBDs) for moving and stationary objects in horizontal, inclined, and off-surface settings within the scope of mechanics topics. The study used a case study design, which is a qualitative research method. The Free-Body Diagram Drawing Scale was used as the data-collection tool. Interviews were also conducted with the prospective science teachers. The Free-Body Diagram Drawing Scale questions varied, covering horizontal and inclined surfaces, as well as off-surface situations. The study data were analyzed to identify prospective science teachers' errors in determining which forces to include in the FBD, drawing the forces' directions, and comparing their magnitudes. Overall, most errors were observed in the inclined-surface questions. Regarding the forces included in the FBD, omitting the friction force, normal force, gravitational force, and the force exerted by the upper object was particularly notable, especially in questions involving inclined surfaces. When determining the directions of the forces to include in the FBD, most prospective science teachers incorrectly determined the direction of the friction force acting on a woman walking on a flat surface. For objects on an inclined surface, errors in determining the direction of the friction force and the normal force were particularly significant. Additionally, extra vectors were added to the drawings where they shouldn't have been. Finally, when comparing force magnitudes, errors increased as the number of forces included in the FBD increased.

Keyword: Errors in drawing free-body diagrams

Introduction

The importance of science subjects in the development of countries is undeniably accepted today. Therefore, educators need to properly structure the teaching processes of science subjects at every level of education. Science subjects predominantly involve abstract concepts. Students, in particular, have difficulty understanding physics subjects due to factors such as the abstract nature of physics concepts, difficulty visualizing them, difficulty applying what they have learned in practice, and difficulty relating the subjects to daily life (Şahin & Yağbasan, 2012). Similar findings are present in other studies (Oon & Subramaniam, 2011; Örnek et al., 2008; Triani & Fahlani, 2024). In this case, for students to learn abstract science concepts, especially physics concepts that they find difficult to understand, in a meaningful and lasting way, they must acquire problem-solving skills in a process that relates these concepts to daily life.

One of the abstract physics concepts that we encounter almost every moment of our daily lives is force. Therefore, understanding the concept of force is crucial for students at all grade levels, especially for prospective teachers who will teach physics. Many university-level textbooks recommend using free-body diagrams to solve problems related to force and motion (Bueche & Jerde, 1995/2003, p. 73; Giancoli, 2023, p. 119; Serway & Jewett, 2004, pp. 123-139). Thus, free-body diagrams are used in university education when teaching force and motion. A free-body diagram (FBD) represents all forces acting on an object as vectors and plays a crucial role in solving physics problems (Serway & Jewett, 2004, pp. 123-139). Thanks to FBD, the system's motion can be

analyzed. The use of representations such as FBD positively contributes to students' attempts to solve force problems (Sirait et al., 2019). Thus, participants who correctly draw the FBD while solving a problem are more successful in problem-solving (Rosengrant et al., 2009). However, research indicates that students struggle with drawing FBDs (Berge & Weilenmann, 2014; Winarno et al., 2019). For these reasons, it is essential for today's prospective science teachers, who will be the future science teachers, to be able to draw free-body diagrams correctly to properly structure the subject of "force and motion" in their minds. Educators need to know which mistakes prospective science teachers make when drawing FBDs, as this will help them structure their teaching.

Previous educational studies involving FBDs have addressed various research objectives. For example, the relationship between prospective physics teachers' views on problem-solving and their ability to solve force problems has been investigated (Sirait et al., 2019). Another example is the interaction patterns among engineering students and the role of FBD in these patterns, examined using a sample question (Berge & Weilenmann, 2014). In another study, research was conducted aiming to contribute to the development of students studying engineering mechanics through an online exam containing various questions (including simple FBD questions) (McCarthy & Goldfinch, 2012). In yet another study, the use of FBD when solving physics problems and the relationship between the quality of the diagrams they draw and their problem-solving success were investigated (Rosengrant et al., 2009). However, studies focusing on free-body diagram drawings and revealing errors in drawings have been quite limited (Durkaya, 2021; Poluakan & Runtuwene, 2018; Temiz & Kızılcık, 2016; Winarno et al., 2019). In this context, the problems experienced by prospective science teachers in drawing free-body diagrams related to Newton's laws were examined using objects from five different visuals (Winarno et al., 2019). The ability of high school students to draw free-body diagrams for an object on a frictional inclined plane was investigated (Temiz & Kızılcık, 2016). The ability of prospective mathematics teachers to draw free-body diagrams for objects on flat and inclined surfaces was investigated (Durkaya, 2021). Although some previous studies have investigated errors in FBD drawings, examining these errors across different physical situations involving both stationary and moving objects may provide a more comprehensive understanding of the difficulties experienced by prospective science teachers. This research aims to identify errors prospective science teachers make when drawing FBDs for moving and stationary objects in different physical situations (horizontal surfaces, inclined surfaces, and off-surface situations) within the scope of mechanics topics. Thus, this study is expected to contribute to the literature by examining errors in identifying forces, determining their directions, adding unnecessary vectors, and comparing force magnitudes across different physical situations within a common analytical framework.

Research Questions

The research question is: "What are the errors made by prospective science teachers when drawing FBDs within the scope of mechanics topics?"

Accordingly, the following sub-research questions were addressed:

1. What errors do prospective science teachers make in identifying the forces that should be included in FBDs?
2. What errors do prospective science teachers make in determining the directions of forces in FBDs?
3. What unnecessary vectors do prospective science teachers include in FBDs?

4. What errors do prospective science teachers make when comparing the magnitudes of forces in FBDs?

Method

This research, conducted to identify the errors made by prospective science teachers when drawing FBDs in mechanics topics, was carried out using a case study design, . A case study is defined as the in-depth description and examination of a limited system (Merriam, 2009). Since this research aimed to identify errors in drawing FBDs, each prospective science teacher's drawings were examined and analysed in detail, and the findings were presented clearly.

Study Group

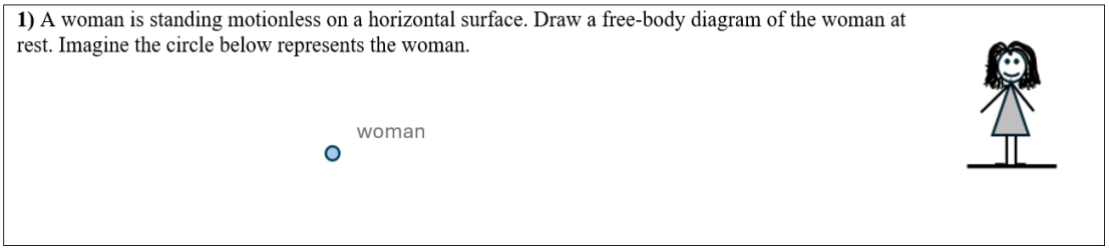
The study group consisted of 38 prospective science teachers enrolled in a Science Education Program at a state university. Of these volunteer participants, 12 were first-year students, nine were second-year students, five were third-year students, and 12 were fourth-year students. All participants received training in free-body diagrams as part of the compulsory Physics 1 course, which covered mechanics topics, during their first year of the program.

Data Collection Tools

In this study, the Free Body Diagram Drawing Scale was used as a data collection tool, and an interview technique was utilized. All prospective science teachers in the study group answered the Free Body Diagram Drawing Scale. When the data obtained from the scale were examined, considering some unclear drawings, unnamed forces, lack of magnitude comparison, and situations where magnitude comparison could not be understood from the lengths of the arrows, interviews were conducted with all participants except one student to clarify the unclear parts.

Free Body Diagram Drawing Scale (FBDDS): The FBDDS scale was developed as part of this research. Initially, nine questions (14 in total, including sub-questions) were created within the scope of mechanics. Opinions were sought from five experts (three in physics education and two in science education) regarding the scale and answer key. Based on expert opinions and suggestions, some adjustments were made to the scale and answer key. The final version of the scale contains nine main questions (14 questions in total, including sub-questions). The questions in the scale cover both moving and stationary objects on horizontal and inclined surfaces, as well as objects that are not in contact with a surface. One of the questions is shown as an example in Figure 1, along with a representative drawing of the shape. The content of all questions is given in Table 1.

Figure 1.
Question 1 in the FBDDS



The content of all questions is given in Table 1.

Table 1.
Content of the questions included in the FBDDS

Category		Question No. Object for which an FBD drawing is requested in the question
Horizontal Surface	Stationary	1. A **woman** standing on a horizontal surface
		3. A book standing on a horizontal surface (There is an orange on the book)
	Moving	2. A **woman** walking on a horizontal surface
		6a. A **sled** moving on a horizontal surface, pulled by a person with a rope parallel to the surface (A woman is sitting on the sled)
Inclined Surface	Stationary	4a. A **child** sitting still on the inclined surface of a slide
		5. A **box** standing on an inclined surface (A cat is sitting on the box)
	Moving	4b. A **child** sliding down an inclined surface
		6b. A **sled** moving on an inclined surface, pulled by a person with a rope parallel to the inclined surface (A woman is sitting on the sled)
Off- Surface Situations	Stationary	7b. A **ball** thrown vertically upwards from below (A FBD drawing is required for the moment the ball reaches its highest point)
		9a. A **monkey** standing still holding onto a rope at one end of a fixed pulley (Many bananas are hanging from the end of a rope dangling from the other end of the pulley, and the system is stationary)
	Moving	7a. A **ball** thrown upwards from below (an FBD drawing is required for a moment when the ball is moving upwards in the air)
		7c. A **ball** thrown upwards from below (an FBD drawing is required for a moment when the ball moves downwards after reaching the highest point)
		8. A **ball** thrown downwards from above (an FBD drawing is required for a moment when the ball is moving downwards)
		9b. A **monkey** moving downwards holding onto a string at one end of a fixed pulley (Fewer bananas are hanging from the end of the string on the other side of the pulley, the system is in motion).

The pilot implementation of the scale was conducted with 10 prospective science teachers, following the same process as the planned main application. No changes were deemed necessary to the questions after the pilot study. Therefore, the data obtained from the pilot study were used as the primary data for this study.

Interview: 37 prospective science teachers participated in the interviews. During the interviews, participants were only asked about the parts of their FBD drawings that were unclear (unnamed forces, unreadable text, magnitude relationships between forces whose magnitudes were unclear or not compared, etc.). Therefore, the interviews conducted with each participant were structured specifically for each participant.

Data Collection Process

The implementation of the FBDDS was conducted online via Microsoft Teams, with all participants in the same meeting. Before the meeting, participants were asked to bring blank paper and pens. At the beginning of the meeting, all the information and items under the "Reminder" heading at the beginning of the scale (Figure 2) were both displayed on the screen and read aloud. This procedure was intended to remind participants of the FBD and emphasize the key points. Then, the questions were shown sequentially on the screen, and participants were asked to draw the FBD for each given object on their papers, indicating the question number. Time was given for all participants

to complete their drawings, question by question. Once the drawings were completed, participants took photos of their papers and sent them to one of the researchers of this study.

Figure 2.
Reminder notes placed before the questions in the FBDDS

REMINDER
Free-Body Diagram: A vector representation that allows the analysis of all forces acting on an object, along with their directions and magnitudes. In other words, it is a diagram that shows all the forces acting on the object in vector form.
Please pay attention to the following points when answering the questions:
1- Indicate which forces the vectors you draw in free-body diagrams represent.
2- Be sure to indicate the directions of the vectors.
3- Draw the vectors in proportion to their magnitudes (if this is not clear from your drawing, list the vectors next to your drawing according to their magnitudes).
4- All surfaces in all questions are frictional. In questions where required, assume that the static/kinetic friction coefficients are less than 1.
5- Neglect air friction for all questions.

Following the implementation of the FBDDS, interviews were conducted online, separately with each participant. Interview durations ranged from 5 to 15 minutes, depending on the participant.

Data Analysis

In this process, the data obtained from the FBDDS and interviews were first transferred to a Microsoft Excel file. A separate page was created for each question in the Excel file, and tables were created for all analyses related to that question. Students were coded as "Ö1-38" and entered into these tables. The tables were finalized after the researchers' made changes deemed necessary during the analysis. Thus, an arrangement was created in which data for all sub-problems could be viewed in a single table, separately for each question. All data from the first nine participants were coded in a coordinated manner by the researchers of this study through consensus. During this process, the coding table was also finalized. The data from the remaining participants were coded individually by one of the researchers. To ensure coding reliability, all data were also individually coded by an expert outside of the researchers. Miles and Huberman's reliability formula ((Agreements)/(Agreements + Disagreements)x100) was used to determine inter-coder agreement (Miles and Huberman, 1994). The inter-coder agreement rate was calculated as 93%. Subsequently, the two coders met online to discuss the conflicting coding points and made adjustments to the coding after reaching a consensus. Data analysis processes were carried out in accordance with the FBDDS answer key. The forces that should be included in the plots according to the FBDDS answer key are indicated with the symbol "√" and given in Table 2.

Table 2.
Forces that should be included in FBDs according to the answer key

Category		Question No. and Object	Normal Force	Friction Force	Gravitational Force	Force exerted by the upper object	Tension
Horizontal Surface	Stationary	1. **Woman** standing	√	-	√	-	-
		3. **Book** with an orange on it	√	-	√	√	-
	Moving	2. **Woman** walking	√	√	√	-	-
		6a. **Sled** pulled by a rope with a woman on it	√	√	√	√	√
Inclined	Stationary	4a. **Child** on a slide	√	√	√	-	-
		5. **Box** with a cat on it	√	√	√	√	-

	Moving	4b. **Child** on a slide	√	√	√	-	-
		6b. **Sled** with a woman on it	√	√	√	√	√
Off-Surface	Stationary	7b. **Ball** in the air (max. height)	-	-	√	-	-
		9a. **Monkey** on a rope	-	-	√	-	√
	Moving	7a. **Ball** in the air (moving upwards)	-	-	√	-	-
		7c. **Ball** in the air (falling downwards)	-	-	√	-	-
		8. **Ball** in the air (thrown downwards)	-	-	√	-	-
		9. **Monkey** on a rope	-	-	√	-	√

The forces in Table 2 are explained below:

- Normal force: This is the force exerted by the ground on the object. Its direction should be drawn perpendicular to and away from the ground surface.
- Friction force: This is the friction force exerted by the surface on which the object rests. Its direction is: (i) opposite to the relative motion between the contact surfaces, if there is relative motion; and (ii) opposite to the tendency of relative motion, if there is no relative motion between the contact surfaces.
- Gravitational force (Object's weight): This is the gravitational force exerted by the Earth on the object. Its direction should always be drawn vertically downward.
- Force exerted by the upper object: When another object is on top of the object whose FBD is drawn, this force represents the resultant contact force exerted by the upper object on the lower object due to its weight (weight of the orange in question 3, weight of the cat in question 5, weight of the woman in question 6). Since the upper objects have zero acceleration and are subjected only to gravitational and contact forces in the situations considered in this study, this resultant force is equal in magnitude to the weight of the upper object and acts vertically downward.
- Tension: For question 6, this is the tension force in the rope caused by pulling the sled. Since the rope is pulled parallel to the surface, the tension force should be drawn parallel to that surface and in the direction of the pull. For question 9, this is the tension force in the rope held by the monkey. Its direction should be drawn upwards.

Important details regarding the data coding processes are given below:

- Participants expressed the same concept/force with different names when specifying vector names. These names were coded under a single expression during the coding process (for example, when representing "normal force," they sometimes used letters such as N and FN, and sometimes used conceptual expressions such as "normal force" or "reaction force" instead of letters). While the data were analyzed using the answer key, forces with different naming conventions were evaluated and coded by considering the context of the drawing and the meaning attributed to the vector by the participant.
- When participants represented two forces with a single vector but explicitly identified both forces in its label, each force was coded separately.
- Errors in the starting points of the vectors in the FBD drawings (starting the friction force vector from the center of the object, starting the weight vector from the part in contact with the ground, etc.) were excluded from the scope of the research. They were therefore not considered in the analysis process.
- In question 9, five participants' drawings were excluded from the overall analysis because they did not conform to the FBD format. Therefore, the number of participants whose drawings were analyzed for this question is 33.

- In questions involving inclined surfaces, the motion conditions specified in each question (e.g., remaining stationary or moving at constant velocity) were taken into account when determining the forces and comparing their magnitudes.

Findings

The study's findings are presented under four subheadings corresponding to the four sub-research questions. The abbreviations Q1, Q2, …, Q14 are used for the questions when presenting the findings.

Errors Related to Determining the Required Forces in the FBD

Table 3 provides details regarding forces that should be included in FBDs but are not. The "-" sign in Table 3 indicates that the relevant force should not be included in the FBD drawn for that question, according to the answer key.

Table 3.
Details regarding forces that should be included in the FBD but are not

Category*		Question No. and Object	Prospective science teachers who did not include the forces that should be present in free-body diagrams									
			Normal Force		Friction Force		Gravitational Force		Force exerted by the upper object		Tension	
			N	%	N	%	N	%			N	%
Horizontal Surface	S	1-**Woman** standing	2	5.3	-	-	0	0	-	-	-	-
		3-**Book** with an orange on it	4	10.5	-	-	2	5.3	5	13.2	-	-
	M	2-**Woman** walking	2	5.3	0	0	0	0	-	-	-	-
		6a-**Sled** pulled by a rope with a woman on it	5	13.2	3	7.9	**9**	**23.7**	**14**	**36.8**	2	5.3
Inclined Surface	S	4a-**Child** on a slide	5	13.2	**16**	**42.1**	0	0	-	-	-	-
		5- **Box** with a cat on it	3	7.9	**7**	**18.4**	2	5.3	**7**	**18.4**	-	-
	M	4b- **Child** on a slide	**8**	**21.1**	2	5.3	0	0	-	-	-	-
		6b-**Sled** with a woman on it	**7**	**18.4**	4	10.5	**9**	**23.7**	**13**	**34.2**	5	13.2
Off-Surface	S	7b-**Ball** in the air (max. height)	-	-	-	-	2	5.3	-	-	-	-
		9a-**Monkey** on a rope	-	-	-	-	0	0	-	-	0	0
	M	7a-**Ball** in the air (moving upwards)	-	-	-	-	0	0	-	-	-	-
		7c- **Ball** in the air (falling downwards)	-	-	-	-	0	0	-	-	-	-
		8- **Ball** in the air (thrown downwards)	-	-	-	-	0	0	-	-	-	-
		9b- **Monkey** on a rope	-	-	-	-	0	0	-	-	0	0

When Table 3 is examined, it is evident that most problems with determining forces occurred in the questions on inclined surfaces (Q4, Q5, and Q6). The following errors stood out in terms of forces:

- Failure to include the friction force for stationary objects on an inclined surface: In Q4a, 42.1% of prospective science teachers and, in Q5, 18.4%, did not include this force. Compared with moving objects on an inclined surface (Q4b: 5.3%, Q6b:

10.5%), more prospective science teachers did not include the friction force for stationary objects in the FBD.

- Failure to include the normal force for objects moving on an inclined surface: Compared to stationary objects (Q4a: 13.2%, Q5: 7.9%) on an inclined surface, more prospective science teachers failed to include normal force in the FBD for moving objects (Q4b: 21.1%, Q6b: 18.4%).
- Failure to include the force acting due to the weight of the top object or the gravitational force acting on the bottom object when there are two objects on top of each other: In each question involving stacked objects (Q3, Q5, Q6a, and Q6b), whether moving or stationary, some prospective science teachers neglected to include the force acting on the object due to the weight of the top object in the FBD. Some also neglected to include the gravitational force acting on the object in the FBD.

A few prospective science teachers in Q6 did not include the tension in the rope that pulled the sled in their FBDs.

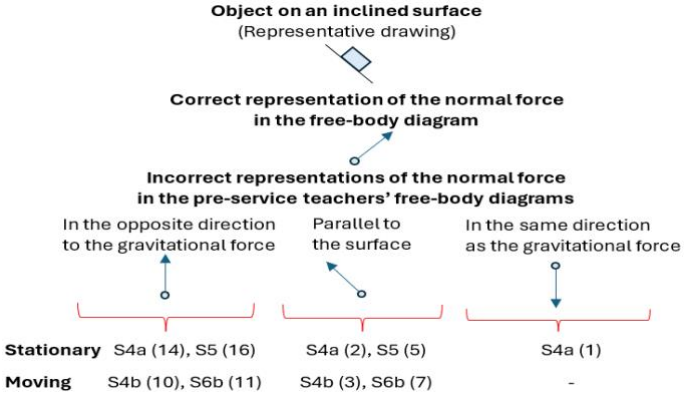
Errors Related to the Directions of Forces in the FBD

In horizontal surface questions, except for Q2, the directions of the forces were generally drawn correctly (Only one prospective science teacher incorrectly drew the direction of the reaction force in the direction of the weight in Q1, Q2, and Q3). For Q2, in which the FBD was to be drawn for a woman walking on a horizontal surface, a particular situation arose. There is no relative motion between the woman's foot and the ground surface, and the friction force acting on the woman by the ground should be drawn in the direction of the woman's movement. However, almost all of the prospective science teachers (36) drew the direction of the friction force acting on the woman during walking as opposite to the direction of movement.

In off-surface situations, it was generally observed that prospective science teachers correctly drew the directions of the forces that should be in the FBD.

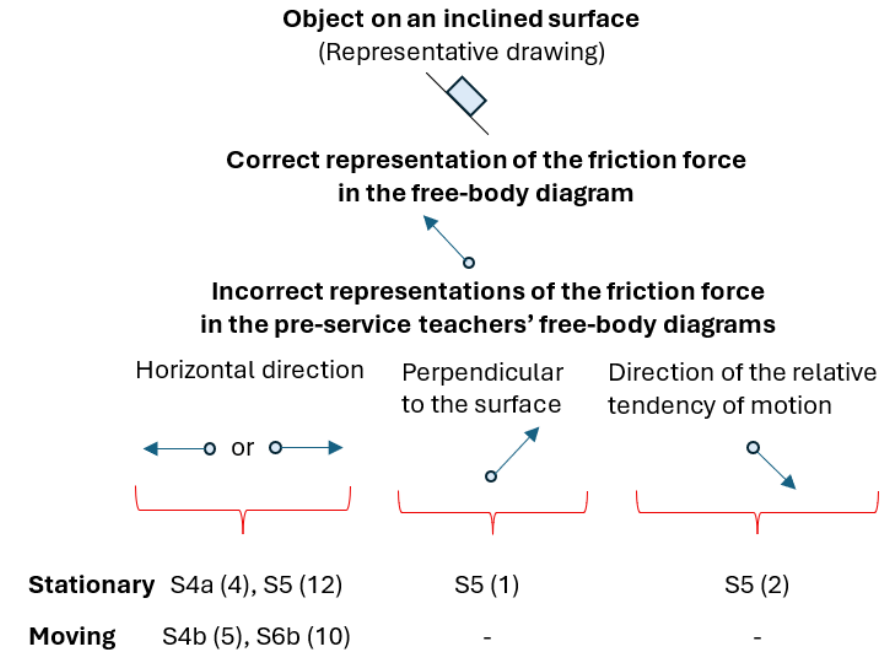
In inclined surface questions, many errors were made regarding directions. Errors related to the direction of the normal force, friction force, and weight are given in Figures 3, 4, and 5. In creating these figures, expressions encompassing all questions were used to highlight the fundamental findings while downplaying the differences in the slope directions of the inclined surfaces in the questions (e.g., "in the opposite direction to the gravitational force," "parallel to the surface," etc.). The numbers in parentheses next to the question numbers in the figures represent the number of prospective science teachers who made the corresponding error.

Figure 3.
Incorrect representations of the normal force.



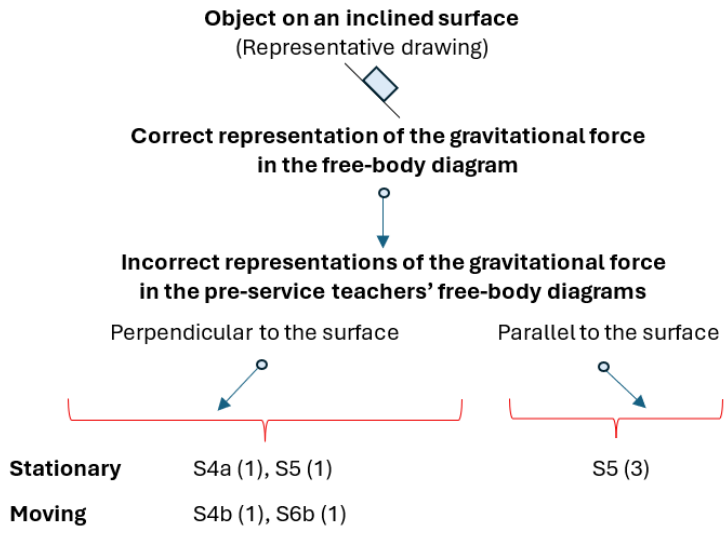
As seen in Figure 3, the most common error regarding the direction of the normal force, both for stationary and moving cases, is showing the normal force in the opposite direction to the gravitational force. Some prospective science teachers also drew the normal force parallel to the surface. One prospective science teacher, in question 4a, drew it in the same direction as the gravitational force.

Figure 4.
Incorrect representations of the friction force



According to Figure 4, the most common error regarding the direction of the friction force is drawing it horizontally. In Question 5, one prospective science teacher drew it perpendicular to the surface, while two other prospective science teachers drew it in the direction of the relative motion tendency.

Figure 5.
Incorrect representations of the gravitational force.



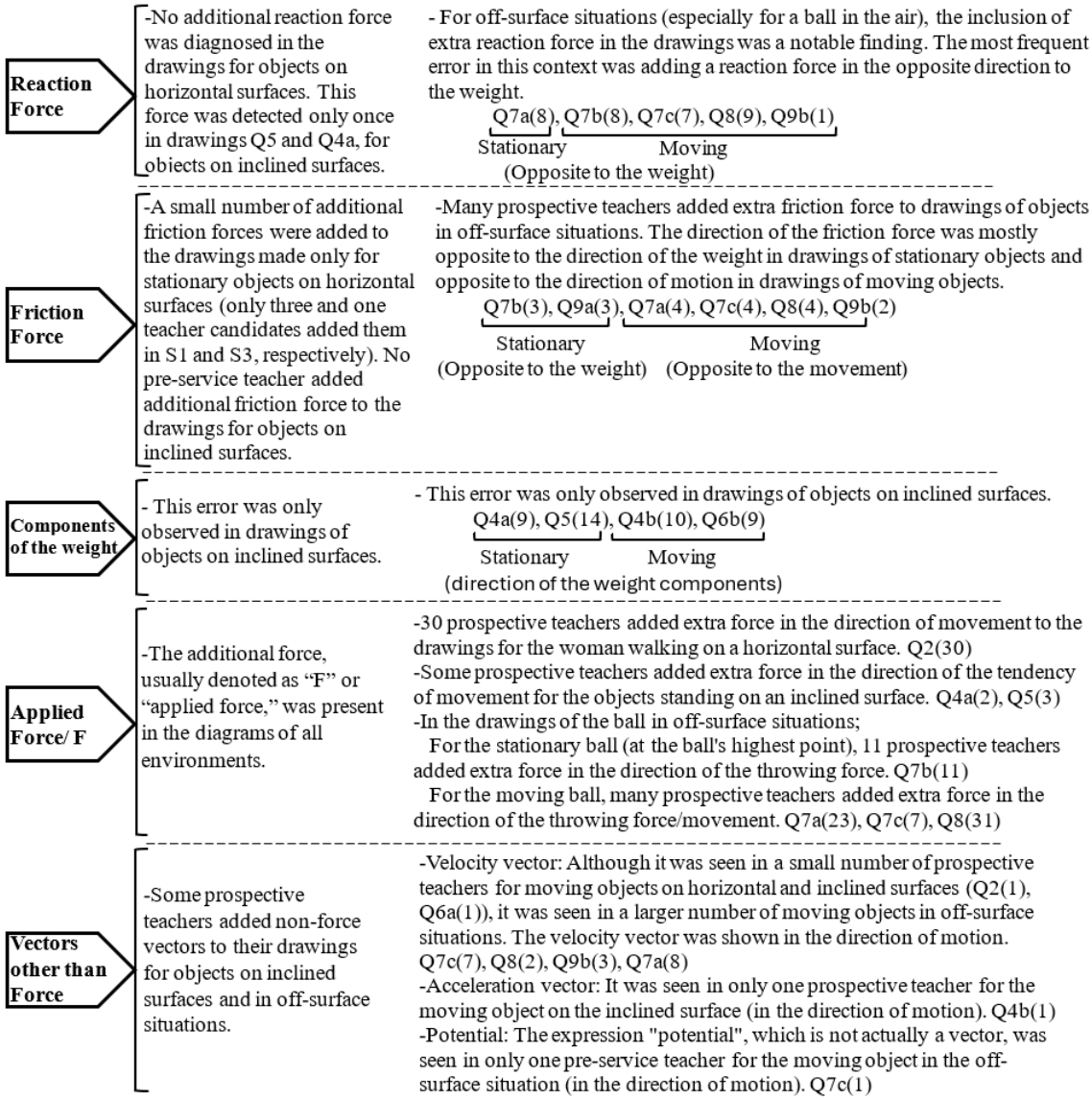
As seen in Figure 5, a few prospective science teachers made errors in the direction of the gravitational force acting on the object. These errors involved drawing the gravitational force perpendicular or parallel to the inclined surface rather than vertically downward.

Additionally, in question 6b, the pulling force exerted by Mehmet (rope tension), which should be drawn parallel to the inclined surface for a sled moving on an inclined surface, was incorrectly drawn by eight prospective science teachers. One drew it in the opposite direction, and the other seven drew it horizontally instead of parallel to the inclined surface.

Vectors Drawn Where They Should Not Be in the FBD

The key findings regarding vectors drawn where they should not be in the FBD are summarized in Figure 6.

Figure 6.
Key findings regarding vectors added to FBD drawings where they should not have been.



As shown in Figure 6, the additional vectors drawn in the FBDs included reaction force, friction force, components of weight, and the applied force F. Additionally, some vectors that do not represent forces (velocity, acceleration, potential) were also included in the drawings.

Errors Made in Comparing the Magnitudes of Forces

Table 4 presents the required magnitude comparisons in the FBD and the number of prospective science teachers who could not make these comparisons or made them incorrectly.

Table 4.
Details regarding comparisons of the magnitudes of the forces

Category		Question	Comparison of Force Magnitudes in the Answer Key	Prospective Science Teachers Who Failed to Make the Correct Comparison	
				N	%
Horizontal Surface	Stationary	Q1	Woman's weight = Normal Force	5	13.2
		Q3	Book's weight + Orange's weight = Normal Force	14	36.8
	Moving	Q2	Woman's weight = Normal Force	7	18.4
		Q6a	Woman's weight + Sled's weight>Friction Force	26	68.4
			Friction Force = Tension	**35**	**92.1**
			Woman's weight + Sled's weight > Tension	**31**	**81.6**
			Friction Force < Normal Force	20	52.6
			Tension < Normal Force	**36**	**94.7**
			Woman's weight + Sled's weight = Normal Force	23	60.5
Inclined Surface	Stationary	Q4a	Child's weight > Friction Force	27	71.1
			Friction Force = Normal Force	**30**	**78.9**
			Child's weight > Normal Force	27	71.1
		Q5	Cat's weight + Box's weight> Friction Force	26	68.4
			Friction Force = Normal Force	**32**	**84.2**
			Cat's weight + Box's weight > Normal Force	27	71.1
	Moving	Q4b	Child's weight > Friction Force	13	34.2
			Friction Force = Normal Force	**35**	**92.1**
			Child's weight > Normal Force	22	57.9
		Q6b	(Woman's weight + Sled's weight)> Friction Force	19	50.0
			Friction Force < Tension	11	28.9
			Woman's weight + Sled's weight > Tension	**31**	**81.6**
			Friction Force < Normal Force	25	65.8
			Normal Force < Tension	23	60.5
			Woman's weight + Sled's weight > Normal Force	**31**	**81.6**
Off-Surface	Stationary	Q7b	No magnitude comparison (single force)	-	-
		Q9a	Monkey's weight = Tension	15	45.5
	Moving	Q7a	No magnitude comparison (single force)	-	-
		Q7c	No magnitude comparison (single force)	-	-
		Q8	No magnitude comparison (single force)	-	-
		Q9b	Monkey's weight > Tension	15	45.5

According to Table 4, a small number of prospective science teachers incorrectly compared magnitudes in the questions involving a woman standing on a horizontal surface (Q1) and a woman walking (Q2) (5 and 7 prospective science teachers, respectively). While the number of incorrect comparisons was higher in the question about a book with an orange on it (Q3) than Q1 and Q2, it remained lower than in most other questions. The general comparison error in these questions was the assumption that weight is greater than the reaction force. The most significant problems regarding magnitude comparisons were observed in the questions involving inclined surfaces. In

questions involving inclined surfaces, high error rates were observed in several force magnitude comparisons. For a ball thrown upwards and a ball thrown from the top of a building (Q7 and Q8), which are off-surface situations, there is no magnitude comparison, as there is only one force (weight) in the FBD to plot. In the question involving a monkey hanging from a rope outside the ground, nearly half of the prospective science teachers incorrectly compared magnitudes in both stationary and moving situations. For the case where the monkey hanging from the rope is at rest (Q9a), the most common error in magnitude comparisons was the assumption that the upward tension force in the rope is greater than the monkey's downward weight. For the monkey hanging from the rope and moving downwards, the errors were mostly due to drawing forces that should not be present in the diagrams.

Discussion

This study investigated the errors made by prospective science teachers when drawing FBDs. During the research process, prospective science teachers created FBDs for stationary and moving objects on horizontal and inclined surfaces, as well as in off-surface situations. The drawings were analysed for errors in determining the required forces, drawing their directions, and comparing their magnitudes.

Errors Related to Determining Forces

When the drawings of prospective science teachers were evaluated for their inclusion of the forces that should be present in the FBDs, it was observed that the most problems occurred in questions involving inclined surfaces. In particular, the omission of the friction force in the FBDs for objects on inclined surfaces was notable. Furthermore, this error was made more often by prospective science teachers with stationary objects on inclined surfaces than with moving objects. Prospective science teachers who made this error with stationary objects may have assumed, as has been found in the literature, that the frictional force does not act on stationary objects (Williams et al., 2003). Another prominent finding was the omission of the normal force in the FBDs for objects on inclined surfaces. This error was more frequently observed in FBDs drawn for moving objects than for stationary objects. Winarno et al. (2019), in their studies with prospective science teachers, and Temiz and Kızılcık (2016), with high school students, examined the FBD drawings made for an object on an inclined surface, not specified as stationary or moving, and found that, as in this study, some students did not show the normal force and friction force in the diagram. Similar findings were determined in FBDs drawn by university students for a block moving on an inclined plane with friction (Poluakan & Runtuwene, 2018). In this research, when two objects are stacked on top of each other, another important finding stands out in the FBDs drawn for both flat and inclined surfaces (for both stationary and moving objects). Many prospective science teachers do not show the force acting on the bottom object due to the weight of the top object in the FBD of the bottom object (some even did not show the gravitational force acting on the object whose FBD was drawn). Therefore, prospective science teachers had difficulties representing the force exerted by the upper object on the lower object in FBDs. Another finding regarding the determination of forces for off-surface objects is noteworthy; in the question of a ball thrown upwards, two prospective science teachers did not draw any vector in FBD when the ball was at its highest point. This finding is consistent with studies in the literature that identified a misconception among students (Atasoy & Akdeniz, 2007; Jimoyiannis & Komis, 2003): that no force acts on a ball at its highest point.

Errors Related to Determining the Directions of Forces

When the drawings were evaluated in terms of determining the directions of the forces that should be present in the FBDs, it was observed that, except for one prospective science teacher, the teachers correctly determined the direction of the reaction force in the drawings made for stationary objects on a flat surface (a standing woman and a book with an orange on it). However, an important issue emerged in the FBDs drawn for the woman walking on a flat surface. Almost all the prospective science teachers added the friction force in the opposite direction of the woman's movement. Various studies in the literature indicate that some students believe, or hold the misconception, that the friction force always acts in the opposite direction of motion (Besson et al., 2010; Canlas, 2021; Carvalho & Sousa, 2005; Chia, 1996; Prasitpong et al., 2010; Wulandari et al., 2017). Therefore, many prospective science teachers might have incorrectly drawn the direction of the friction force due to the misconception that it always acts in the opposite direction of motion. In the inclined surface questions, many prospective science teachers incorrectly drew the directions of the forces in all questions. Errors in the directions of the normal force and the friction force were significantly more frequent than in the others. The most common error in determining the direction of the normal force for objects on an inclined surface is drawing the normal force in the opposite direction to the weight, instead of perpendicular to the ground. This error may be due to prospective science teachers first learning to draw FBDs on flat surfaces (where the normal force is always opposite to the weight). A similar finding was observed in a study by Temiz and Kızılcık (2016) involving the high school level. Other errors, although few in number, in determining the direction of the normal force were drawing it parallel to the ground or in the direction of the weight. In the study conducted by Temiz and Kızılcık (2016), some students drew the direction of the normal force parallel to the ground on an inclined surface. It is thought that these errors may stem from a lack of knowledge among students. Regarding the direction of the friction force, the most common error for objects on an inclined surface is drawing it horizontally. The reason for this error may be that prospective science teachers have difficulty thinking in three dimensions when they remove the object from the system to draw FBDs. Similar results are reported in the literature (Durkaya, 2021; Temiz & Kızılcık, 2016). Although few, some prospective science teachers also drew the direction of the weight inwards from the ground, either perpendicular or parallel to the ground. It is thought that these errors may stem from students' difficulty thinking in three dimensions or from a lack of knowledge. In questions involving off-surface situations, it was generally observed that prospective science teachers correctly drew the directions of the forces that should be present in the FBDs.

Additional Vectors Drawn

When the drawings were evaluated for the forces shown, which should not be present in FBDs, it was observed that for stationary objects on a flat surface (a standing woman and a book with an orange on it), few prospective science teachers drew additional forces. However, in the question about the walking woman on the horizontal surface, most prospective science teachers incorrectly drew the friction force backward and added an extra forward force F. Also, in questions involving inclined surfaces, a significant number of prospective science teachers drew extra forces F in the direction of motion for moving objects and in the direction of the tendency of motion for stationary objects. Therefore, consistent with the findings in the literature, prospective science teachers may hold the view that "motion implies force" (Galili & Bar, 1992). The misconception that "motion implies force" is among the most common misconceptions regarding the concept of force (Liu & Fang, 2016). Many prospective science teachers also made similar mistakes in questions involving off-surface environments (particularly

ball questions). During the upward movement of a ball thrown upwards and the downward movement of a ball thrown from a building, most prospective science teachers drew an additional force in the direction of motion. This error may be related to the misconception of "motion implies force," as well as to another misconception in the literature, "the force applied to an object at the beginning of its movement continues to act throughout the movement" (Atasoy & Akdeniz, 2007; Şimşek et al., 2019). For balls thrown upwards and downwards, some prospective science teachers have also added an extra force in the direction of motion, which they call a "reaction force." It is thought that one reason for this error may be students' mistaken understanding of action-reaction pairs. The literature indicates that students have difficulty identifying action-reaction force pairs related to Newton's 3rd Law (Low & Wilson, 2017). Another finding regarding added forces is that an extra frictional force is sometimes included, especially in questions involving a ball thrown into the air and sometimes in questions involving a monkey on a rope. In the questions involving a ball thrown into the air, likely the emphasis on "neglecting air friction for all questions" before the test began was forgotten/ignored. However, in the monkey-on-a-rope question, the inclusion of an additional friction force in the drawing, alongside the rope's upward tension, when the monkey is both stationary and moving, may stem from a lack of information.

A common issue across all inclined plane questions was the inclusion of both the weight and its components in the drawings. Temiz and Kızılcık (2016) obtained similar results in their study involving high school students on inclined, friction-bearing surfaces. This finding suggests that students cannot fully understand the relationship between the force and its mathematical components. Indeed, Aviani et al. (2015) stated that in inclined plane problems, students can consider the weight force and its components as separate forces, and that separating forces into components can lead some students to blur the distinction between real forces and mathematical representations. Therefore, it is important to emphasize in the teaching process that students should only show forces resulting from physical interactions when creating free-body diagrams. Furthermore, this research revealed that vectors other than forces (velocity, acceleration, and potential) were added to the drawings (often in the direction of motion). The situation of drawing a non-force quantity (acceleration) in a free-body diagram was also encountered in the study conducted by Temiz and Kızılcık (2016) with high school students on a frictional inclined plane. It is thought that the reason for this error may be that the fact that only forces should be included in the free-body diagram was not taken into consideration or that concepts such as acceleration and potential were not fully understood.

Errors Related to Comparing the Magnitudes of Forces

When the drawings were evaluated for magnitude comparisons, it was observed that the questions with the fewest errors were those containing only one comparison (Q1: standing woman, Q2: walking woman, Q3: book with an orange on it, Q9: monkey on a rope). It was found that as the number of forces required in the FBD increased, requiring strong mathematical and physical knowledge, prospective science teachers experienced greater difficulties comparing the magnitude of forces (across all questions on an inclined surface and the sled question on a horizontal surface). No studies examining the magnitudes/comparisons of forces in FBD drawings were found in the literature. Therefore, these findings are considered valuable.

Limitations of the Study

This study has several limitations. First, the participants were 38 prospective science teachers from a single university; therefore, caution is needed when transferring the findings to other educational contexts. Second, the analysis focused on the physical

situations included in the Free Body Diagram Drawing Scale, so errors arising in other situations were not examined. Finally, errors related to the starting points of force vectors were excluded from the analysis. Accordingly, the findings do not encompass all possible errors in drawing free-body diagrams.

Conclusion

When the findings of this research are evaluated in general, it is evident that most prospective science teachers have difficulty drawing FBDs. Therefore, it is highly likely that most prospective science teachers will have problems in problem-solving processes. Indeed, studies in the literature have found that students have problems with problem-solving processes involving FBD drawings (Berge & Weilenmann, 2014; Durkaya, 2021; Winarno et al., 2019; Pranata et al., 2017). It is thought that errors in FBD drawings may be related to misconceptions/erroneous information about force and motion. So, it is considered important for educators to structure their teaching by placing greater emphasis on FBDs. Indeed, students who correctly draw the FBD in problem-solving usually solve the problem correctly, whereas those who draw it incorrectly usually solve it incorrectly (Rosengrant et al., 2009). The findings of this research can guide educators in identifying the points that require particular attention and focus in the teaching and problem-solving processes for movement topics.

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