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IMPROVING SECONDARY SCHOOL STUDENTS' REPRESENTATIONAL COMPETENCE IN FORCE AND MOTION CONCEPTS

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Abstract:
Representational competence is essential in interpreting the representations such as verbally expressed laws, mathematical equations, diagrams, graphs, charts and animations involved in physics which are related to abstract concepts. One aspect of this competence with relevance to physics education is the students' ability to understand the physics-specific representations in relation to their physical and real-world applications which encompass to static as well as dynamic entities. In this study, attention has been paid to developing, validating and utilizing a lesson-specific assessment tool to identify students' difficulties in understanding such representations encountered in selected Grade 10 physics-related science lessons presently taught in Sri Lankan government schools, namely, Resultant force, Newton's laws of motion, Friction and Equilibrium of forces. The tool has been administered as an online test for a sample of 72 selected Grade 11 students who have already completed the lessons in their schools at Grade 10. It consists of 28 multiple-choice questions. It showed a mean score of 52.65% with a standard deviation of 24.94%. The tool gave high reliability (Cronbach's alpha value of 0.795). By analyzing the students' performance at individual questions of the tool it revealed that the students have certain difficulties in understanding the representations such as the inability to determine the line of action of a force related to a given real-world situation, inability to predict the nature of the motion of an object if the object is acted upon by a constant force continuously, inability to identify difference between the action force and the reaction force mentioned in Newton's third law of motion which act in two distinct objects, and marking such forces in a free body force diagram. The extent to which the prescribed curriculum materials help the students to overcome these difficulties has been evaluated and some suggested teaching-learning activities have been proposed to improve the students' representational competence.

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1. Introduction

In physics education, the skills of interpreting representations such as diagrams, graphs and mathematical equations with an insight into their interactions and link to observational and experimental outcomes play a major role in understanding abstract concepts and symbolic mathematical expressions. These skills collectively known as representational competence greatly facilitates the smooth understanding of concepts in physics (Kozma & Russell, 2005; Kohl & Finkelstein, 2005; Kohl & Finkelstein, 2006; Küchemann et al., 2021). Step-by-step development or the logical sequence of presenting the concepts by using appropriate representations helps students to visualize the related subject matter (Piyatissa, Johar & Tarofder, 2018).

The extent to which the student can correctly understand the representations in physics is an indicator of the student's conceptual understanding. Therefore, it is necessary to employ novel methods in representation in designing learning activities as well as in student assessment tools, the latter for the purpose of highlighting areas if any for further improvements in representation methods. Doing this at the introductory level in physics courses, that is, Grades 10 and 11 in Sri Lankan context (General Certificate of Education-Ordinary Level) is very important as losing confidence of their ability to grasp the subject at this stage can have serious consequences. Therefore, this study is designed to achieve the following specific objectives.

1) To utilize an assessment tool to identify secondary school students' basic misconceptions in understanding the representations used in the Force and Motion concepts in Grades 10 and 11 classes;
2) To evaluate the extent to which the prescribed curriculum materials help the students to overcome the misconceptions;
3) To suggest suitable activities to be included in the new curriculum materials to enrich the students' representational competence in this area.

2. Literature review

2.1 External representations and representation modes

Representations are twofold; external representations and internal representations (Gilbert, 2010). In science education, external representations can be physical objects, experimental setups, diagrams, graphs, mathematical equations, principles, or laws expressed in written or verbal form, etc., as opposed to the internal representations which are mentally built by the student corresponding to the external representations (Gilbert, 2005). Gilbert (2010) summarized the external representations into five representation modes, namely, (1) the material/ concrete (physical models/ setups), (2) the verbal (written/ spoken expressions), (3) the symbolic (standard symbols/ mathematical equations), (4) the visual (diagrams, graphs, videos, animations, simulations, etc.) and (5) the gestural (teacher's gestural expressions). In the following discussion, the term 'representations' usually means external representations unless otherwise specified.

2.2 Toggling between representation modes

In understanding a particular science (physics) concept, students may need to toggle between different representation modes, for example, in understanding Newton's second law of motion, the student needs to understand the second law expressed verbally (the verbal mode), an experimental setup used to demonstrate the law (the material mode), the law expressed using a mathematical equation (the symbolic mode), a diagram or a video used to represent the law (the visual mode), sequence of presenting them being dependent on the teacher's choice and the students' background. Each individual representation has its unique advantages for conceptual understanding (Küchemann et al., 2021).

2.3 Representations and models

The use of representations is needed to introduce the models in physics. A model can be a simplified illustration of a complex natural phenomenon or an abstract concept behind such phenomenon (Piyatissa, Johar & Tarofder, 2018). To teach students the physical models and the conceptual models, the teacher can use the representation modes appropriately (Gilbert, 2005). The student should be helped to visualize the models in three representation levels: the macroscopic, the microscopic, and the symbolic (Johnstone, 1993).

2.4 Physics-specific learning difficulties with representations

Students have subject-specific learning difficulties with representations (Kohl & Finkelstein, 2005). Detecting the presence of such difficulties is useful for educators to design suitable strategies to overcome this issue by utilizing relevant representations in proper sequence with necessary explanations in the teaching and learning process.

Hestenes, Wells and Swackhamer (1992) mentioned that certain common-sense feelings (layman's feelings) on the operation of forces on objects and the effects of it can contradict Newtonian principles. For example, the researchers identified such misconceptions in their famous Force Concept Inventory (FCI), a kind of diagnostic tool.

> "*Only active agents exert forces, motion implies active force, no motion implies no force, velocity is proportional to applied force, acceleration implies increasing force, force causes acceleration to terminal velocity, active force wears out*."(p.2)

Further, they pointed out that the conventional teaching methods unless they are not suitably adjusted to take care of these misconceptions help a little in bridging the gap irrespective of how experienced the instructor is. However, addressing such misconceptions collectively would be more effective rather than addressing each one separately making the system of Newtonian concepts a single coherent unit (Hestenes, Wells & Swackhamer, 1992).

In order to identify the difficulties mentioned above including any others of similar nature, the teacher has to make use of suitable lesson-specific assessment tools capable of identifying the difficulties in understanding the representations both traditional as well as developed by the teacher. By analysing the performance of such tools the teacher can effect suitable changes by adding further representations such as computer-aided learning materials (Piyatissa, Johar & Tarofder, 2018; Piyatissa, Johar & Tarofder, 2019) and explaining historical background, etc.

Piyatissa and Waduge (2022) developed and validated an assessment tool (referred to as '*Grade 10 - Force and Motion – Visualization Related Questions*') to assess students' representational competence in four physics-related science lessons taught in Grade 10 classes. The objective of designing such a tool was to use it as an effective formative assessment tool to be used along with the proposed '*Grade 10 Force and Motion Module*' under new General Education Curriculum reforms in Sri Lanka which was initially planned to be implemented in the year 2023 which was held up due to unavoidable circumstances. This particular course module contains four lessons, namely, (1) Resultant force, (2) Newton's laws of motion, (3) Friction, and (4) Equilibrium of forces.

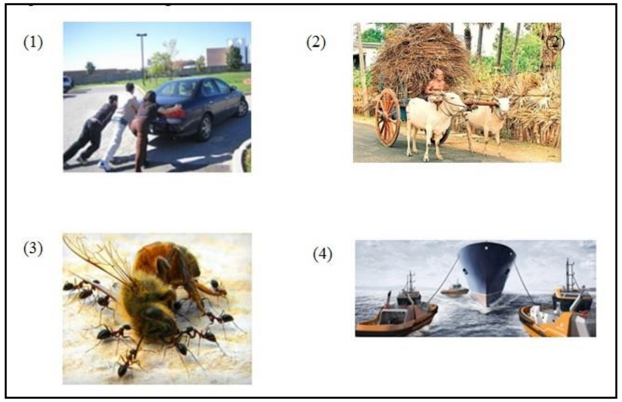
The content of the four lessons in this proposed new curriculum is almost the same as the existing ones and therefore, the tool can be used with the existing science curriculum as well. This assessment tool consisted of 22 test items (questions) covering multiple-choice type, short answer type and those requiring drawing diagrams and marking the forces. Some questions contained sub-questions. With all the sub-questions, it had 32 questions. Some of the items were newly developed for better focusing, and some were adopted/ adapted from validated sources (Piyatissa & Waduge, 2022). It was administered to 87 Grade 10 students in 2022. It showed higher reliability (Cronbach's alpha = 0.86). The analysis of students performance disclosed that the participated students had certain learning difficulties in understanding lesson-specific representations such as identifying the lines of action of forces applied on an object, marking forces on free body force diagrams, realizing that constant force continuously applied on an object results in acceleration of the object, the action and reaction pair of forces under Newton's third law of motion act on two distinct objects and the weight of an object acts vertically downwards. For ease of administering, the need of converting the tool to an online test has arisen. Therefore, in the present study, the assessment tool (test) has been converted to one which can be administered as a Google form. In this conversion, certain improvements have also been affected. Some new items related to real-world applications have been introduced, some items to test the prior knowledge as a revision has been introduced and some items have been made more structured.

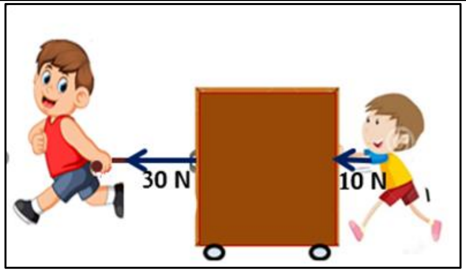
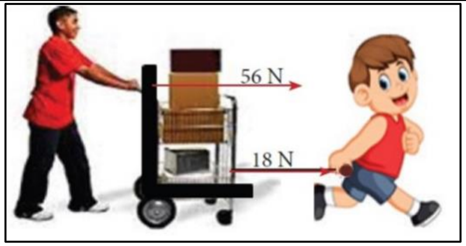
3. Material and Methods

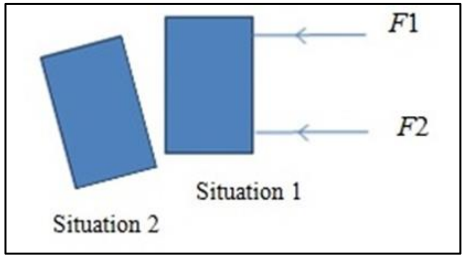
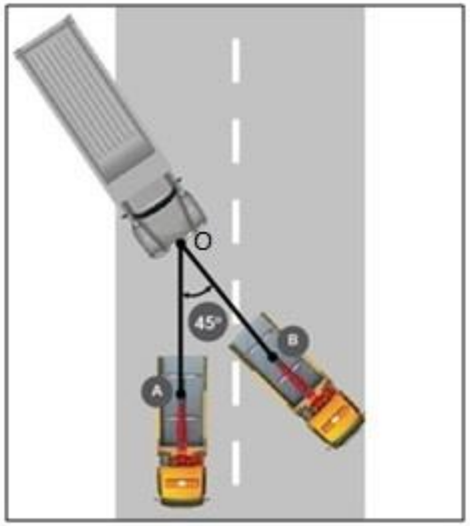
3.1 Test item development

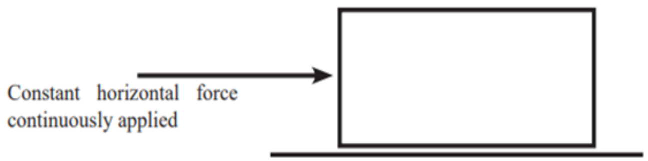
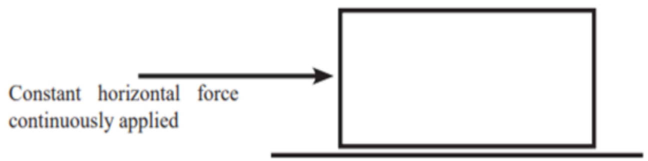
Based on the analysis of students' performance on the assessment tool (Piyatissa & Waduge, 2022), a new assessment tool has been redesigned, keeping in mind the representations suitable for on-line testing. The test items (questions) of the new tool are given in Table 1 with the representations to be interpreted and the expected outcome for each item. The tool consists of 28 items. Out of 28 items, 7 are for Resultant force (items R1-R7), 14 are for Newton's law of motion and Friction (items N1-N14), and 7 are for Equilibrium of forces (items E1-E7). The sources of the items are given in Table 2.

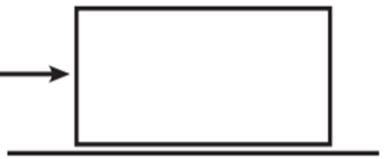
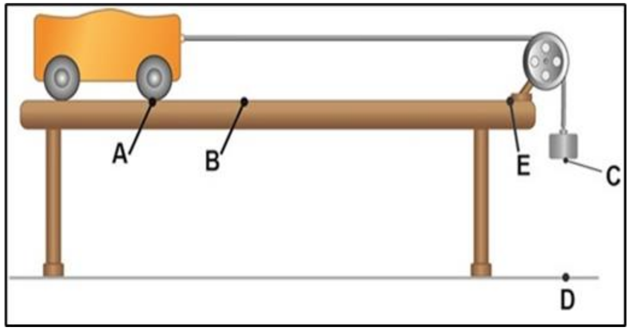
Table 1: Notable expected outcome(s) connected with interpreting the representations in the test items

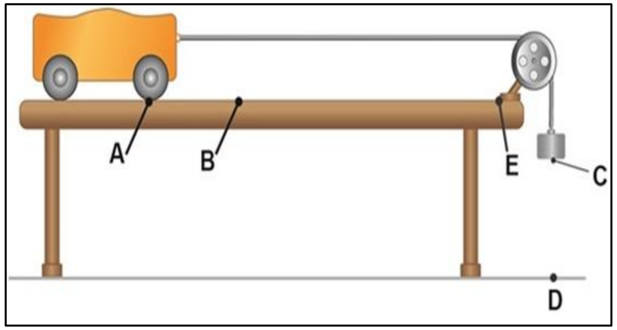
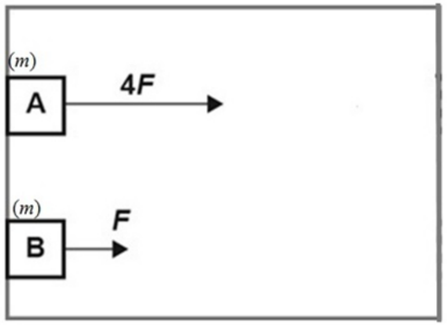
Item no.	Expected outcome	Representation to be interpreted	Question related to the representation
R1	Determining whether two given forces applied on an object are collinear, parallel, or inclined.		Which of the following statement is correct regarding the two forces applied by student A and student B? (1) The forces applied by A and B are collinear and they act in the same direction. (2) The forces applied by A and B are collinear and they act in opposite directions. (3) The force applied by A and the force applied by B are inclined to each other. (4) The force applied by A is parallel to the force applied by B and they act in the same direction.
R2	Identifying instances where two parallel forces are applied on an object in real life.		Which of the following situations is more related with the effect of the resultant of two parallel forces acting in the same direction? 

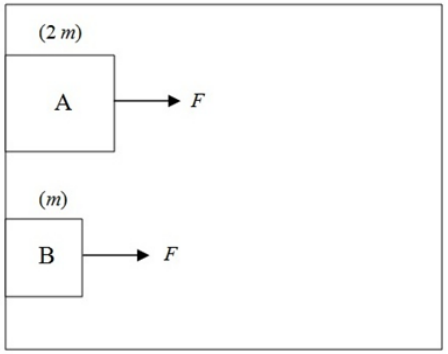
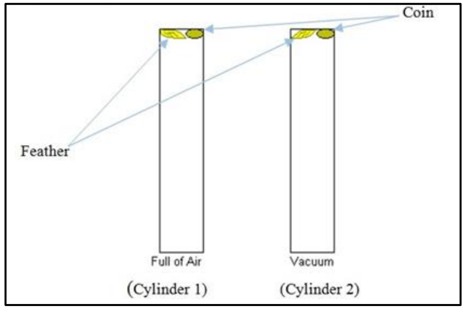
Item no.	Expected outcome	Representation to be interpreted	Question related to the representation
R3	Determining the resultant of two collinear forces acting in the same direction.		What is the resultant of the two forces applied by the two children? (1) 40 N, along ← direction (2) 40 N, along → direction (3) 20 N, along ← direction (4) 20 N, along → direction
R4	Determining the resultant of two parallel forces acting in the same direction.		What is the resultant of the two forces applied by the two children? (1) 74 N, along ← direction (2) 74 N, along → direction (3) 38 N, along ← direction (4) 38 N, along → direction
R5	Determining the resultant of three parallel forces considering two at a time.		The diagram below shows the top view of a block having a rectangular shape. Assume that it lies on a frictionless flat surface. Three horizontal forces are acted upon the block as shown in the diagram. The resultant of these forces is, (1) zero. (2) 20 N, along ← direction. (3) 20 N, along → direction. (4) 40 N, along ← direction.

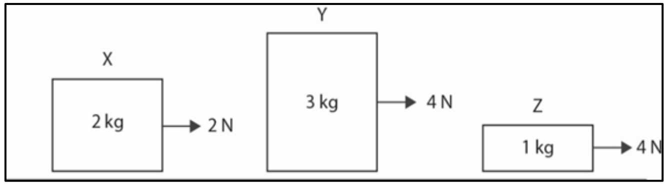
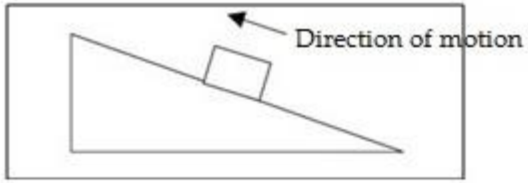
Item no.	Expected outcome	Representation to be interpreted	Question related to the representation
R6	Predicting the effect of applying two parallel forces of different magnitudes to a heavy object ($F1 > F2$).		Two parallel forces $F1$ and $F2$ are applied to a box placed on a rough uniform horizontal surface resulted in moving the box from situation 1 to situation 2 which are of small distance apart (an upper view is shown in the figure). Regarding the magnitude of $F1$ and $F2$, which statement is true out of the following four? (1) $F1 < F2$ (2) $F1 = F2$ (3) $F1 > F2$ (4) Given data is not sufficient to come to a conclusion.
R7	Determining the direction of the resultant of two inclined forces.		A long truck has gone out of the road and fallen into a ditch. Two breakdown vehicles are used to take out the truck from the ditch as shown in the diagram below. Ends of two strings are attached to the two breakdown vehicles at A and B. The other end of each string is attached to the truck at O. When the truck is pulled by the breakdown vehicles using the strings as shown in the diagram, the truck may move along, (1) OA. (2) OB. (3) a direction between OA and OB. (4) a direction outside BOA.

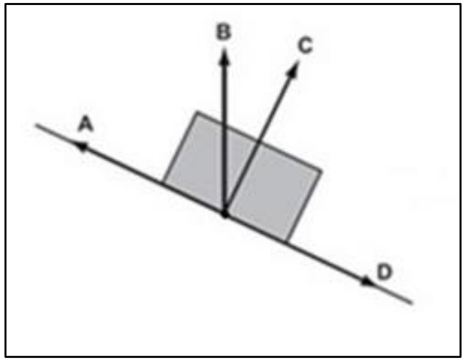
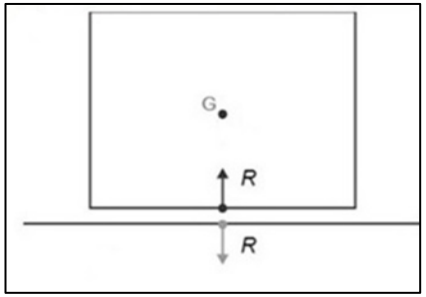
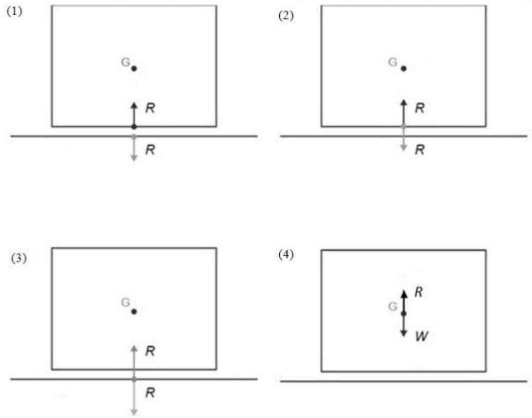
Item no.	Expected outcome	Representation to be interpreted	Question related to the representation
N1	Predicting the effect of applying a constant force continuously to an object on a rough surface.		A constant horizontal force is continuously applied to a wooden block placed rest on a horizontal flat surface which is long and evenly rough. The constant force being continuously applied is greater than the limiting frictional force between the block and the surface, and results in motion of the object. Assume that the air resistance to the motion is negligible. Which of the following statements is correct regarding the motion of the wooden block during the time the constant force is being applied? (1) It moves with a uniform velocity. (2) It accelerates and then moves with a uniform velocity. (3) It moves with a uniform acceleration. (4) It accelerates, then moves with a uniform velocity and then decelerates.
N2	Predicting the effect of suddenly releasing that force.		While the block is in motion as mentioned in Q1 (Item N1), assume that the applied force is suddenly removed. Then, which of the following statements is correct regarding the motion of the block after the sudden removal of the force on it. (1) It keeps on moving with a uniform velocity. (2) It moves with a uniform deceleration. (3) It comes to rest at the moment the force is removed. (4) It keeps on accelerating with a lower acceleration.

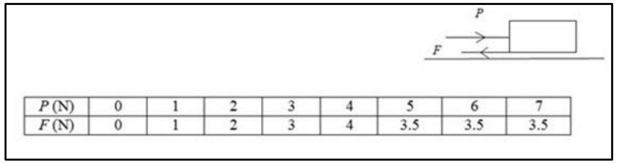
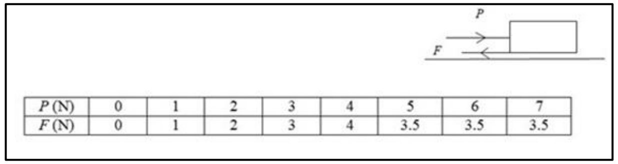
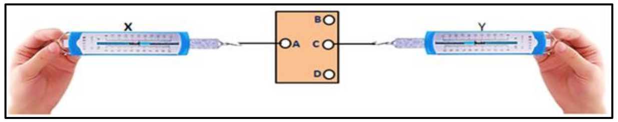
<table>
<tr><th>Item no.</th><th>Expected outcome</th><th>Representation to be interpreted</th><th>Question related to the representation</th></tr>
<tr><td>N3</td><td>Predicting the same if the table surface is smooth.</td><td>
</td><td>What would happen to the motion of the block you explained in Q2(Item N2) if the flat surface were smooth?
(1) It comes to rest at once when the force on the block is removed.
(2) It starts to decelerate at the moment the force on the block is removed and comes to rest afterwards.
(3) It keeps on moving uniformly with the velocity it gained when the force on the block is removed.
(4) It travels uniformly with the velocity it gained when the force on the block is removed, and decelerates afterwards.</td></tr>
<tr><td>N4</td><td>Determining the nature of the force applied on the trolley in two lengths AB and BE ($F_{AB} > 0$, $F_{BE} = 0$).</td><td>
</td><td>The diagram shows an experimental setup containing a trolley kept on a horizontal smooth tabletop. One end of a light unstretchable string is attached to the trolley. The string goes over a smooth pulley fixed to the edge of the table and a weight is hung on the other end of the string as shown. After the weight is released from rest at C, it hits the ground at D given that, AB = CD.
Assume that air resistance is negligible.
Let F_{AB} and F_{BE} be the unbalanced forces acting on the trolley in its motion from A to B and from B to E respectively. Which of the following statements is true regarding the unbalanced force applied on the trolley in the two lengths AB and BE along the table?
From A to B   From B to E
(1) $F_{AB} = 0$ $F_{BE} = 0$
(2) $F_{AB} = 0$ $F_{BE} > 0$
(3) $F_{AB} > 0$ $F_{BE} = 0$</td></tr>
</table>

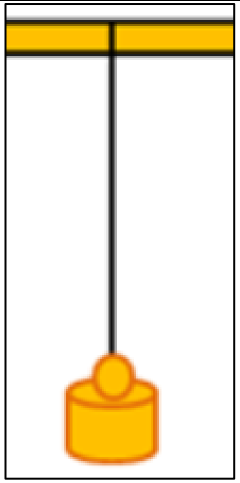
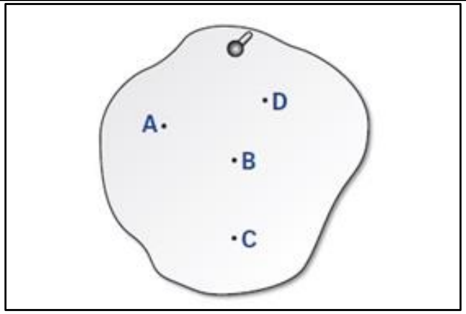
Item no.	Expected outcome	Representation to be interpreted	Question related to the representation
			(4) $F_{AB} > 0$ $F_{BE} > 0$
N5	Determining the nature of motion based on Item N4 (AB: uniform acceleration, BE: uniform velocity).	 	Which of the following statements is true regarding the motion of the trolley from A to B and from B to E in Q4 (Item N4) above? From A to B — From B to E (1) The trolley travels with a uniform velocity. — The trolley does not travel. (2) The trolley travels with a uniform velocity. — The trolley decelerates. (3) The trolley travels with a uniform acceleration. — The trolley travels with a uniform velocity. (4) The trolley travels with a uniform acceleration. — The trolley does not travel.
N6	Predicting the effect of increasing the force on acceleration, keeping the mass constant ($a \propto F$, held m constant) (Newton's second law of motion)	 	The masses of two wooden blocks, A and B, are equal. They are kept at rest close to one edge of a flat horizontal table surface. The friction between the blocks and the table surface is negligible. The diagram shows a view taken over the table. The blocks are pulled by two different horizontal forces. The force on A is four times the force on B and both the forces are applied in the same direction as shown in the diagram. Which of the following statements is correct regarding the acceleration of the two wooden blocks A and B? (1) Accelerations of both A and B are zero. (2) Acceleration of A is one fourth that of B. (3) Acceleration of A is equal to that of B. (4) Acceleration of A is four times that of B.

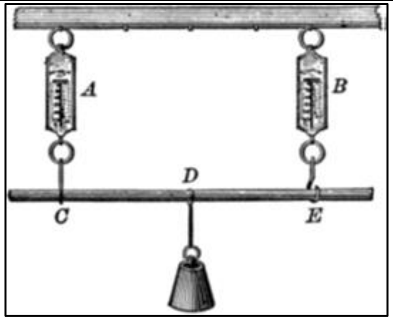
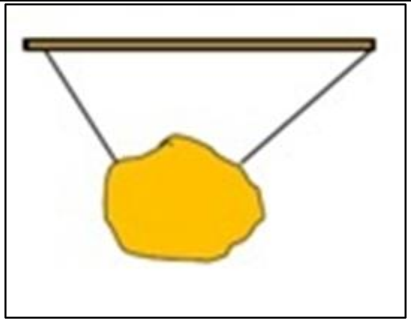
Item no.	Expected outcome	Representation to be interpreted	Question related to the representation
N7	Predicting the effect of increasing the mass on acceleration, keeping the force applied constant ($aa \propto \frac{1}{m}$, held $F\ F$ constant) (Newton's second law of motion)		If the masses of two wooden blocks A and B in Q6 (Item N6) are such that the mass of A is twice and the forces on the blocks are equal as shown in the diagram, which of the following statements is correct regarding the acceleration of the two wooden blocks A and B? (1) Accelerations of both A and B are zero. (2) Acceleration of A is half that of B. (3) Acceleration of A is equal to that of B. (4) Acceleration of A is twice that of B.
N8	Understanding that gravitational acceleration, $aa = gg = \frac{F}{m}\frac{F}{m}$ is constant when the object is released from rest near the ground level if the air resistance is ignored. (Newton's second law of motion)		A coin and a feather kept in a cylinder are allowed to fall from rest at the same time from their top positions shown in the diagram. The first cylinder has been filled with air and the second cylinder has been evacuated. Which of the following statements is correct regarding the motion of the coin and the feather? (1) In both the cylinders, the coin and the feather reach the bottom at the same time. (2) In both the cylinders, the coin reaches the bottom before the feather. (3) The coin reaches the bottom first only in the second cylinder. (4) Both the coin and the feather reach the bottom at the same time only in the second cylinder.

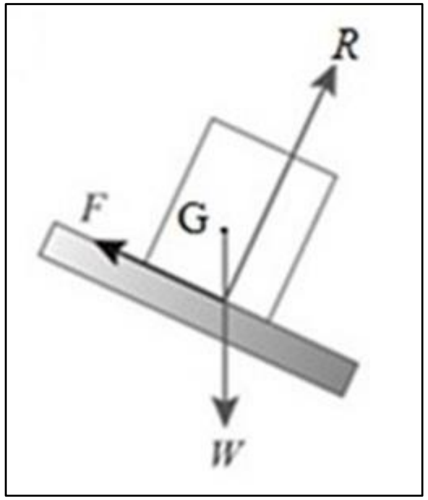
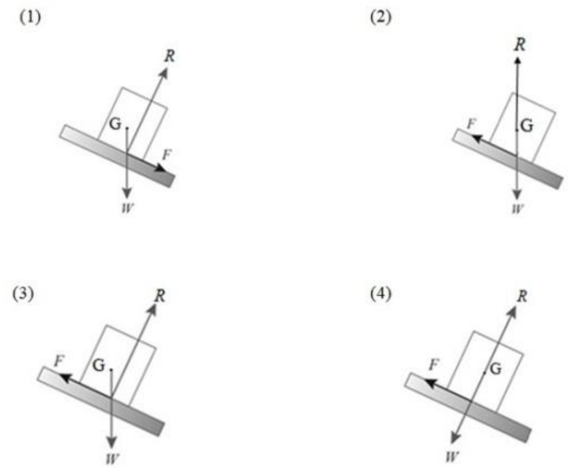
Item no.	Expected outcome	Representation to be interpreted	Question related to the representation
N9	Comparison of accelerations of three objects using $a\ a = \frac{F}{m}$ (Newton's second law of motion)		The diagram below shows three situations where three horizontal forces are applied on three objects X, Y and Z resting on a smooth horizontal surface. The diagram shows a cross-sectional view of the objects and the magnitudes of the applied forces. The objects with the maximum acceleration and the minimum acceleration respectively are (1) X and Y. (2) X and Z. (3) Z and X. (4) Y and Z.
N10	Determining the direction of the force of dynamic friction and the direction of the force of gravity on the wooden block.		A block of wood is pushed on up a rough surface with a slope as shown in the diagram. Which of the following options gives the correct the directions of the dynamic friction and the force of gravity acting on the block? Direction of force of dynamic friction — Direction of force of gravity (1) Upwards parallel to the slope — Downwards perpendicular to the slope (2) Upwards parallel to the slope — Downwards parallel to the slope (3) Downwards parallel to the slope — Vertically downwards (4) Downwards parallel to the slope — Normal to and towards the slope.

Item no.	Expected outcome	Representation to be interpreted	Question related to the representation
N11	Determining the direction of normal reaction		A body stays at rest on a ramp with a rough surface as shown in the diagram. In which direction does the normal reaction force act? (1) A (2) B (3) C (4) D
N12	Identifying action and reaction pair of forces (Newton's third law of motion)		A wooden block rests on a horizontal flat surface of a table. The normal reaction on the block from the table is *R*. The centre of gravity of the block is indicated by G. The weight of the block is *W*. Which of the following diagrams correctly show an '*action and reaction pair of forces*' as mentioned in Newton's third law of motion? 

Item no.	Expected outcome	Representation to be interpreted	Question related to the representation
N13	Determining the dynamic frictional force		An external horizontal force, *P* is applied on an object which is on a rough horizontal plane. The frictional force applied on the object by the horizontal plane is *F*. The table given below shows how this frictional force, *F* varies with the horizontal external force, *P*. Assume that the air resistance is negligible. What is the dynamic frictional force applied on the object by the horizontal plane? (1) 0 N (2) 3 N (3) 3.5 N (4) 4 N
N14	Determining the nature of the motion of the block if *P* is kept at 7 N continuously (Newton's second law)		In Q13 (Item N13), if the external horizontal force *P* is kept constant at 7 N once it comes to 7 N as given in the table, which of the following statements is correct regarding the motion of the object? (1) It travels with a uniform velocity. (2) It accelerates. (3) It decelerates. (4) Without knowing the mass of the object it is unable to come to a conclusion.
E1	Justification of conditions for equilibrium under two forces		The light plastic plate shown in the figure is in equilibrium (the plate is kept horizontal and view taken from straight above the plate is shown). If the reading of newton balance X is 5 N, what is the reading of the newton balance Y? (1) 0 N (2) 2.5 N (3) 5 N (4) 10 N

Item no.	Expected outcome	Representation to be interpreted	Question related to the representation
E2	Identifying the two forces applied on the object and justification of conditions for equilibrium under two forces		The diagram shows a weight hung using a string. Under how many forces the weight is in equilibrium? (1) One (2) Two (3) Three (4) Four
E3	Identifying the centre of gravity and linking it with the conditions for equilibrium under two forces		A student has hung a uniform laminar vertically by a small nail O as shown in the diagram below. Out of points A, B, C and D, which point can be the centre of gravity of this laminar? (1) A (2) B (3) C (4) D

Item no.	Expected outcome	Representation to be interpreted	Question related to the representation
E4	Identifying the three parallel forces applied on the object and justification of conditions for equilibrium under three parallel forces		The diagram shows a mass suspended on a light rod is hung using two newton balances. Under how many forces, the rod is in equilibrium? (1) One (2) Two (3) Three (4) Four
E5	Identifying the three inclined forces applied on the object and justification of conditions for equilibrium under three inclined forces		The diagram shows how a metal lamina is hung using two strings. Under how may forces the lamina is in equilibrium? (1) One (2) Two (3) Three (4) Four

Item no.	Expected outcome	Representation to be interpreted	Question related to the representation
E6	Identifying the lines of action of weight, normal reaction and the friction on an object placed on a rough inclined plane at equilibrium and justification of conditions for equilibrium under three inclined forces.	 	A block of wood is at rest on a ramp with a rough surface. The forces acting on the block are the weight *W* of the block, the friction *F* between the block and the ramp, and the normal reaction force *R* exerted by the ramp. The centre gravity of the block is marked as G. In which diagram, the forces, *W*, *R* and *F* are marked correctly? 

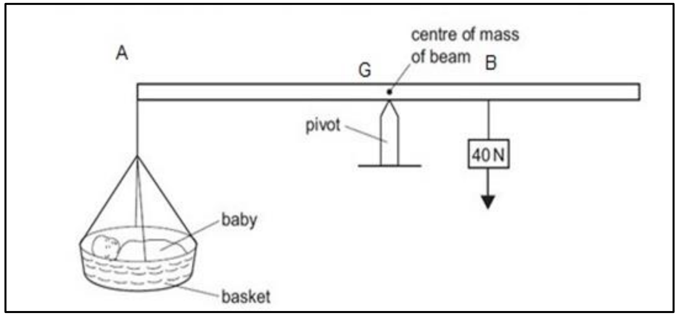
Item no.	Expected outcome	Representation to be interpreted	Question related to the representation
E7	Justification that the clockwise moments around a fix point, are equal to the anticlockwise moments if the object is at equilibrium.		The diagram shows a balance being used to find the weight of a baby. The weight of the basket can be ignored. At the equilibrium position shown in the diagram, GA distance is greater than GB distance. The beam is uniform and it is pivoted from its centre of gravity, G. Which of the following statements is correct regarding the weight of the baby? (1) The weight of the baby is less than 40 N. (2) The weight of the baby is 40 N. (3) The weight of the baby is more than 40 N. (4) It is impossible to tell the weight of the baby without a scale on the beam.

Table 2: Source of test items

Item no	Source
R1	Grade 10 - Force and Motion – Visualization Related Questions (Piyatissa & Waduge, 2022)
R2	Newly developed
R3	Grade 10 - Force and Motion – Visualization Related Questions (Piyatissa & Waduge, 2022)
R4	Grade 10 - Force and Motion – Visualization Related Questions (Piyatissa & Waduge, 2022)
R5	Adapted from IGCSE Physics course Book, General Physics MCQs in the CD-ROM, Q8 (Sang, 2011)/ Used in Grade 10 - Force and Motion – Visualization Related Questions (Piyatissa & Waduge, 2022)
R6	Newly developed
R7	Adapted from Cambridge IGCSE Physics 0625 Paper 31 Q4 June 2009/ Used in Grade 10 - Force and Motion – Visualization Related Questions (Piyatissa & Waduge, 2022)
N1	Newly developed
N2	Newly developed
N3	Newly developed
N4	Newly developed
N5	Adapted from Grade 10 – Force and Motion – Visualization Related Questions (Piyatissa & Waduge, 2022)
N6	Adapted from Grade 10 - Force and Motion – Visualization Related Questions (Piyatissa & Waduge, 2022)
N7	Newly developed
N8	Newly developed
N9	Adapted from School Grade 11 Science Term Test Paper of Term 1 – March 2017, conducted by the Western Provincial Department of Education, Sri Lanka / Used in Grade 10 - Force and Motion – Visualization Related Questions (Piyatissa & Waduge, 2022)
N10	Newly developed
N11	Adopted from Cambridge OL Physics 5054/11 Paper 1– 2013 May/June, Q5/ Used in Visual-Perceptual Assessment Tool (Piyatissa, Johar & Tarofder, 2019)
N12	Adapted from Visual-Perceptual Assessment Tool (Piyatissa, Johar & Tarofder, 2019)
N13	Adapted from Visual-Perceptual Assessment Tool (Piyatissa, Johar & Tarofder, 2019)
N14	Newly developed
E1	Adapted from Grade 10 - Force and Motion – Visualization Related Questions (Piyatissa & Waduge, 2022)
E2	Newly developed
E3	Adapted from IGCSE Physics course Book, General Physics MCQs in the CD-ROM Q9 (Sang, 2011)/ Used in Grade 10 - Force and Motion – Visualization Related Questions (Piyatissa & Waduge, 2022)
E4	Adapted from Grade 10 - Force and Motion – Visualization Related Questions (Piyatissa & Waduge, 2022)
E5	Adapted from Grade 10 - Force and Motion – Visualization Related Questions (Piyatissa & Waduge, 2022)
E6	Adapted from the book, 'O Level Physics MCQ Hot Spots 1000 Frequently Examined Questions', Red Spot Publications, Q42 on p.35 (Lim, 2015)/ Used in Grade 10 - Force and Motion – Visualization Related Questions (Piyatissa & Waduge, 2022)
E7	Adapted from Cambridge International General Certificate of Secondary Education specimen paper 0625/1 (for examinations from 2016) Q8

Expert validation of the test items on this online assessment tool was done with the assistance of three subject experts. Whether the test items in the tool are in agreement with the representations to be interpreted and the corresponding expected learning outcomes as per Table 1 and whether the items are compatible with the present Grade 10 Science syllabus (National Institute of Education, 2015) were thoroughly checked in this expert validation process ensuring the construct validity of the tool.

3.2 Student sample and administering the tool

The on-line version of the assessment tool has been sent to selected grade 11 students who follow Science in English medium at their schools studying at Chilaw Education Zone in North-western Province and Ratnapura Education Zone in Sabaragamuwa Province in Sri Lanka through their school science teachers, as a Google form, with the assistance of two In-service Advisors for the Science subject in the respective education zones (during June 2023). The students voluntarily participated in the research. Seventy-two (72) students participated. Grade 11 students were selected for the study as they had completed the four lesson topics in their routine school schedule when they were in their Grade 10 class. In this sample, 39 were girls and 33 were boys.

4. Results and Discussion

The mean score for this online version of the test (tool) was 52.65% with a standard deviation of 24.94%. It showed a Cronbach's alpha value of 0.795. Therefore, the tool is reliable as its original version. Table 3 shows the lesson-wise performance for the tool.

Table 3: Lesson-wise performance in the tool

Name of the lesson(s)	Mean score (%)	Standard deviation (%)
Resultant force	68.42	26.22
Newton's laws of motion and Friction	41.04	20.56
Equilibrium of forces	60.10	22.95

Table 3 shows that the students' performance is around 40% for Newton's laws of motion and Friction. It is lower than the other two lessons. The percentage of students who correctly answered each item of the tool is given in Table 4.

Table 4: Percentage of students who correctly answered the items (questions) in the assessment tool

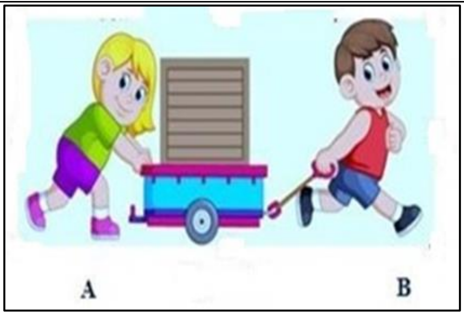
Name of the lesson(s)	Item no.	Percentage of students correctly answered the question
Resultant force	R1	18.18
	R2	59.09
	R3	92.42
	R4	89.55
	R5	86.36
	R6	57.58
	R7	75.76
Newton's laws of motion and Friction	N1	19.70
	N2	30.30
	N3	21.21
	N4	37.50
	N5	44.44
	N6	73.44
	N7	63.08
	N8	39.34
	N9	66.67
	N10	30.65
	N11	35.38
	N12	19.05
	N13	75.38
	N14	18.46
Equilibrium of forces	E1	84.13
	E2	65.08
	E3	84.13
	E4	55.56
	E5	65.63
	E6	17.74
	E7	48.44

Table 4 shows that the percentage of students who correctly answered the items R1, N1, N2, N3, N4, N8, N10, N11, N12, N14, and E6 are below 40%. Out of them, for the items R1, N1, N12, N14 and E6, the percentage of students correctly answered is below 20%. The items showing low performance (below 40%) will be discussed below. How the students selected the four options will be discussed for some of these low-performing items. It will be discussed how the existing curriculum materials help the students to overcome the difficulties and new activities will be suggested to overcome the difficulties wherever appropriate.

4.1 Item R1: Identifying the line of action of two forces applied on an object and hence determining whether the two forces are collinear, parallel or inclined

The way the students have selected the options shows that the majority of them have no clear idea of visualizing the line of action of a force as only 18% of the students have provided the correct answer to the item. Table 5 shows how the students selected the options in item R1.

Table 5: Selection of options by the students for item R1

<table>
<tr><th>Item (Question) in brief
(Item R1)</th><th>Option</th><th>Percentage of students who selected the option</th></tr>
<tr><td rowspan="4">

The forces applied by student A and student B are...</td><td>(1) The forces applied by A and B are collinear and they act in the same direction.</td><td>48.48</td></tr>
<tr><td>(2) The forces applied by A and B are collinear and they act in opposite directions.</td><td>1.52</td></tr>
<tr><td>(3) The force applied by A and the force applied by B are inclined to each other.</td><td>18.18*</td></tr>
<tr><td>(4) The force applied by A is parallel to the force applied by B and they act in the same direction.</td><td>31.82</td></tr>
</table>

*(3) is the correct option

The existing Grade 10 Science syllabus and the Teacher's Guide (National Institute of Education, 2015), and the Grade 10 Science textbook (Educational Publication Department, 2015) do not provide learning outcomes, guidelines, or learning activities related to this.

4.1.1 Suggestions to overcome the difficulty

Before introducing the Resultant force to the students, providing the prior knowledge necessary to identify the line of action of a force is essential. Then the student will be able to identify whether two forces applied on an object are collinear, parallel, or inclined. It is suggested to provide the exercises showing diagrams of applying two forces to an object and ask the student to draw the line of action of the forces by dotted lines and then identify whether the two forces are collinear, parallel, or inclined. Such a suggested activity is given in Figure 1.

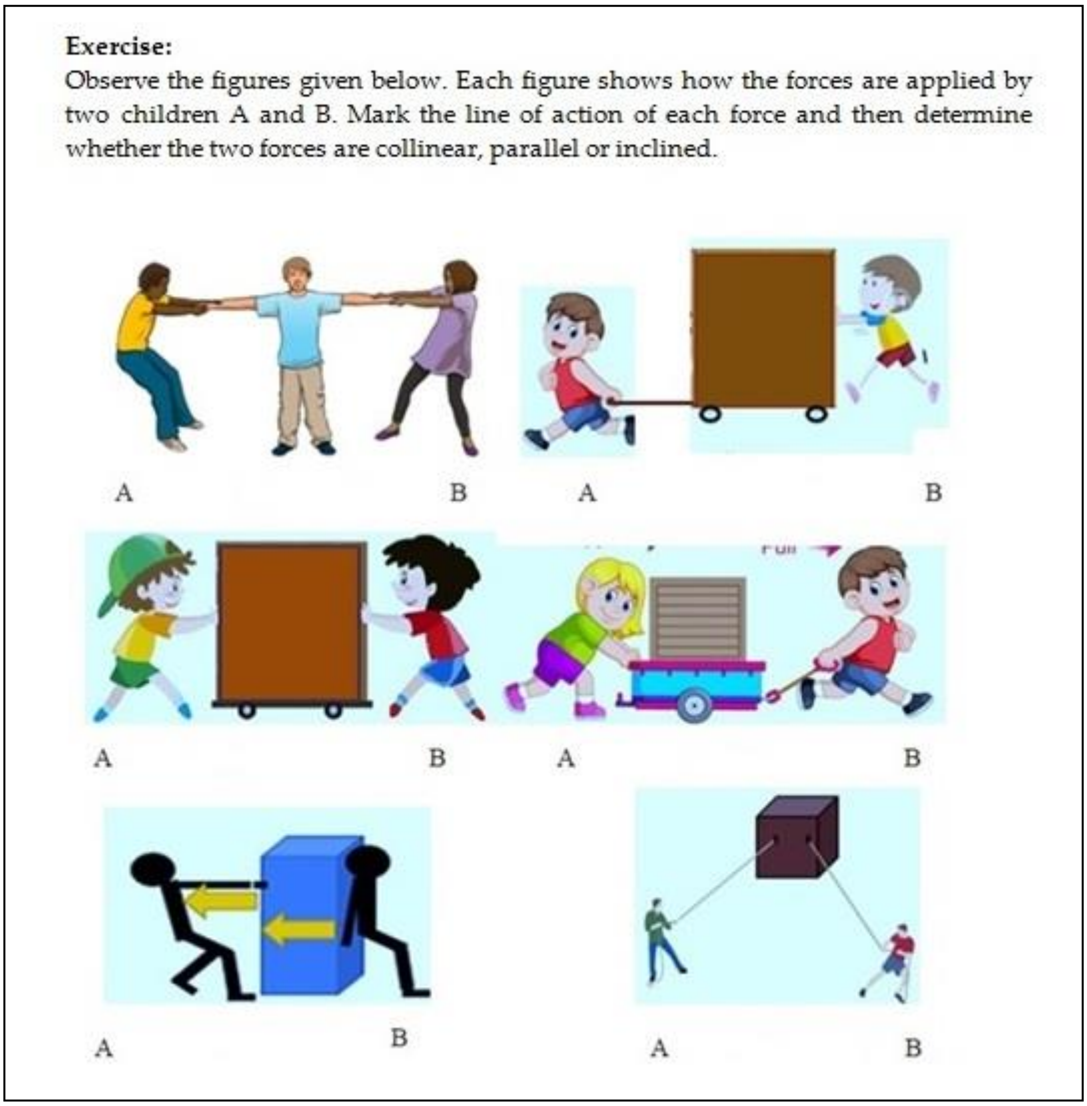


Figure 1: An exercise to identify the lines of action of forces

Necessary clarifications by the teacher, drawing the diagrams on a whiteboard/ smart board can be effective in helping the students to get familiar with this kind of representation. Further, a simple interactive computer simulation programme can also be developed to engage the students in the above-like activities.

4.2 Items N1, N2, N3, N4 and N14: Visualizing Newton's first and second laws of motion

Items N1, N2, N3, N4, and N14 are related to Newton's first and second laws of motion which show low performance by the students. Here the basic problem is that the students are not familiar with the Newtonian way of visualizing and interpreting the forces and effects of the forces. The majority of the students have the misconception that applying a constant unbalanced external force on an object results in the object moves with uniform velocity. Further, most of the students have no clear idea of what is meant by a smooth surface and its effect on the forces applied on the object moving on the surface. In item N1 (Table 1), the student is asked to predict the nature of the motion of an object placed on a rough flat surface, where a constant force is being applied to the object. The object should move with uniform acceleration. Only around 20% of the students were able to provide the correct answer. If they were unable to answer item N1, they would be unable to correctly answer the items N2 and N3, which are related to item N1. In answering item N3, the student needs to recall Newton's first law of motion. In item N14 also, the effect of applying a constant unbalanced external force is inquired by the student in a different context. Hestenes, Wells, and Swackhamer (1992) mentioned that this kind of misconception is very common irrespective of the teacher or the country where Newtonian mechanics are taught because certain common-sense feelings about moving objects lead to such misconceptions. Therefore, rather than finding the reason why the students came up with wrong answers through further item analysis or interviewing the students to trace their thinking, it would be effective to teach the students in a way such misconceptions would not arise at the very beginning Newtonian mechanics is introduced to them at the secondary school level. The existing textbook has not adequately touched this issue. Some of the suggested activities designed to help students to overcome this kind of misconception with instructions to the teacher are discussed below.

4.2.1 Suggestions to overcome the difficulties

Certain instructions to the teacher, worth of considering when the Newton's first and second laws are first introduced to the secondary school students are given below.

- Ensure that the students have the necessary prior knowledge of the definitions of velocity and acceleration.
- Convince the students through a discussion by giving out suitable instances that unless an external unbalanced (resultant) force is acted upon, the objects at rest continue to stay at rest and the objects in motion will continue their motion in uniform velocities.
  Examples:
  - Ask the student what will happen when a wooden block placed on a table is pushed forward by applying a force parallel to the table surface horizontally and then the force is released?
  - Show how the forces are acting on the block by a diagram.
- Enquire from the students the nature of the motion of the wooden block (object) if the table surface is smooth (that is if there are no frictional forces acting between the table surface and the object). When pushing the wooden block, the student might mistakenly conclude that motion needs force. In fact, being not aware of the hidden force of friction may lead to this misconception. To move the block, the push force must be large enough to overcome the friction between the floor and the block. If the floor is slippery, then the friction is low and so only a small push is needed to move the block. If we can remove friction, the link between force and motion can be more easily studied.

- Demonstrate this using the Linear air track. Linear air track is a way of removing friction. Tiny air jets support the rider just above the track. Once set moving, the rider moves at steady velocity along the track. It moves equal distances in equal times so its velocity is constant (Figure 2).

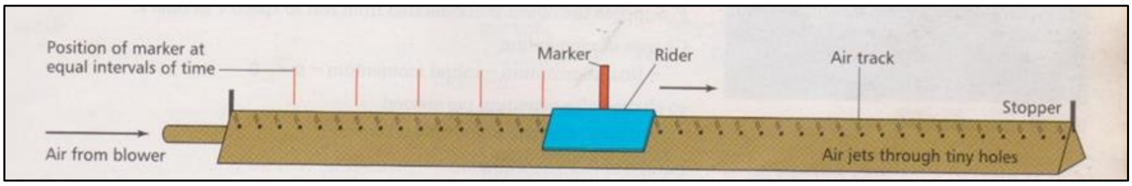


Figure 2: Linear air track

- Introduce Newton's first law of motion.
  - Present Newton's first law of motion verbally and explain it.
  - Conduct a discussion with students to convince them of Newton's first law of motion by providing suitable examples. (eg. elaborating the demonstration using the linear air track, discussion on how travelling in uniform velocity under no unbalanced external force saves fuel in space travelling like journeys from the Earth to Mars)
  - Elaborate that the general link between force and motion is not that force is needed to maintain motion. It is that force is needed to change motion. That is, to change the velocity of an object, the object must be acted on by an unbalanced force (by a resultant force). If there is no resultant force on an object, its velocity must stay the same. If there is a resultant force on an object, its velocity must change.
- Introduce Newton's second law of motion.
  - Demonstrate through a suitable simple activity that applying an unbalanced external force to an object causes it to accelerate. Conduct a discussion to confirm this. (This provides a background to Newton's second law of motion.)
  - Conduct a practical activity like the one given below to demonstrate Newton's second law of motion (Figure 3).

    Part I: Investigating how the change in velocity increase varies according to the unbalanced force whenever (during) the increase in the unbalanced force acted on an object having a constant mass.

    Part II: Investigating how the change in acceleration varies according to the mass, whenever (during) increasing of the mass of an object on which the unbalanced force is acted upon it is constant.
  - Guide the student to derive the equation $F = ma$, based on the findings of the practical activity.

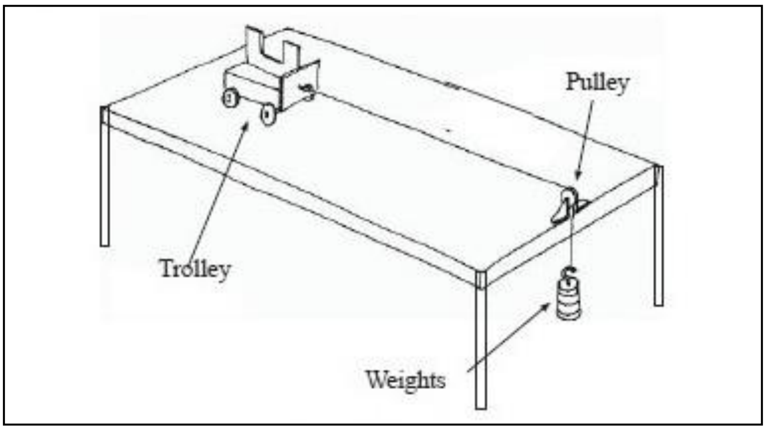


Figure 3: Practical activity to demonstrate Newton's second law of motion

- Engage the student in an interactive simulation like the one given below where the student can change the force applied on the object, the mass of the object, and friction of the floor, and can see how the acceleration changes by looking at the speedometer on top of the screen (Figure 4). The student can understand the effect of applying a continuous force to an object and demonstrate *F*= *ma* (i.e. Newton's second law of motion). By making the friction 'none' in the simulation, the student can visualize Newton's first law of motion. This simulation helps students to understand the representations tested in the items N1, N2, N3, N4, and N14 easily.

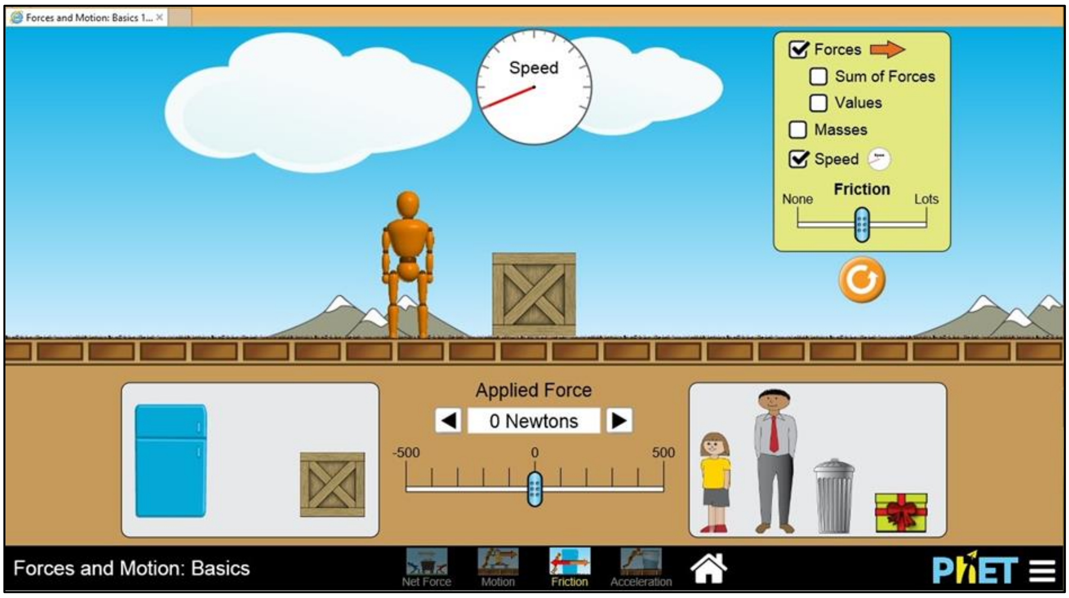


Figure 4: PHET Interactive simulation to demonstrate force and motion
Source: https://phet.colorado.edu/sims/html/forces-and-motion-basics/latest/forces-and-motion-basics_all.html

The above-mentioned suggested teaching-learning activities are some examples of how verbal, concrete, visual, and symbolic modes of representation (Gilbert, 2010) can be used to help the students to understand the representations involved in Newton's first law of motion and Newton's second law of motion so that certain common misconceptions of the subject matter can be avoided.

4.3 Item N8: Free fall of objects near the Earth's surface (Newton's second law of motion)

The common-sense feeling is that the heavy objects must reach the ground first when the objects of different masses are released from the rest at the same height. This item was introduced to trace that misconception. Only around 35% of the students were able to provide the correct answer to the item. The two objects of different masses raised to the same height must reach the ground at the same time if released from rest. This is because the acceleration due to gravity which is equal to $a = g = F/m$ is constant. According to this equation, F adjusts so that the ratio F/m remains constant.

4.3.1 Suggestions to overcome the difficulty

It is suggested that the teacher can do a whole class demonstration using a fall tube like the one shown below (Figure 5). A coin and a feather are placed in a tube which can be tightly closed and air inside the tube can be removed (evacuated). Before removing the air in the tube, the student can see that the coin reaches the bottom of the tube first when both objects are allowed to fall free from the top end of the tube. After removing the air inside the tube, they can see that both the objects reach the bottom of the tube at the same time.

Figure 5: Coin and feather experiment

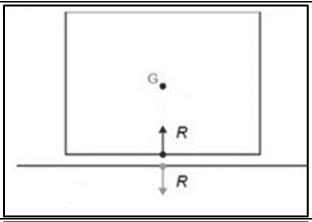
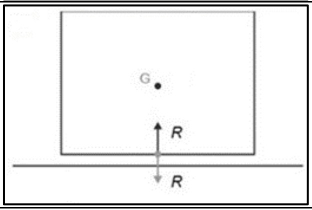
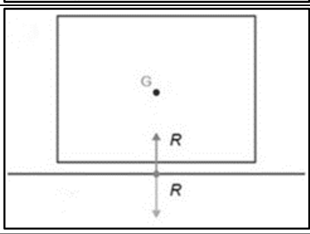
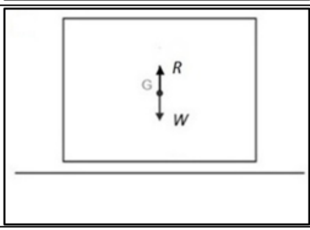
Followed by this demonstration, the teacher can conduct a discussion justifying the equation $g = F/m$, derived from Newton's second law of motion (linking the concrete mode with the symbolic mode). In case the teacher does not have the facilities to physically demonstrate the experiment, the teacher can use a video clip (the visual mode) to demonstrate the experiment.

4.4 Item N12: Newton's third law of motion

Items N10, N11, and E6: Marking the forces acting on an object (wooden block) placed on an inclined plane

Item N12 tests whether the student understands that action force and reaction force mentioned in Newton's third law of motion act on two distinct objects. Only around 19% of the students were able to provide the correct answer. Table 6 shows how the students selected the options.

Table 6: Selection of options by the students for item N12

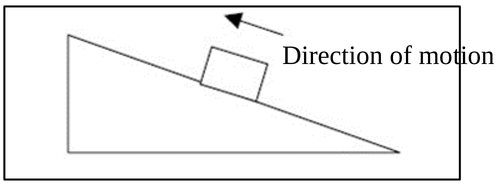
Item (Question) in brief (Item N12)	Option	Percentage of students who selected the option
Which of diagram correctly shows an 'action and reaction pair of forces' as mentioned in Newton's third law of motion?		19.05*
		11.11
		19.05
		50.79

*Option (1) is the correct option.

According to Table 6, nearly 50% of the students think that the two forces, the weight (*W*) of the block and the normal reaction on the block (*R*) are a pair of action and reaction forces mentioned in Newton's third law of motion. They are not aware that the action force and reaction force mentioned in the third law act on two different objects. The existing Grade 10 Science textbook (Educational Publication Department, 2015) does not pay attention to the action and reaction pair of forces on an object placed on a flat horizontal surface. Only the forces acting on an object relevant to its force equilibrium placed on a flat horizontal surface are discussed under the lesson 'Equilibrium of forces'. Suggestions to overcome this misconception are presented after discussing items N10, N11, and E6.

Item N10 tests whether the student knows that friction acts in the opposite direction to the direction of motion (or to the direction the object tends to move) and the weight acts vertically downwards. Only around 30% of the students correctly answered the item. Table 7 shows how the students selected the options.

Table 7: Selection of options by the students for item N10

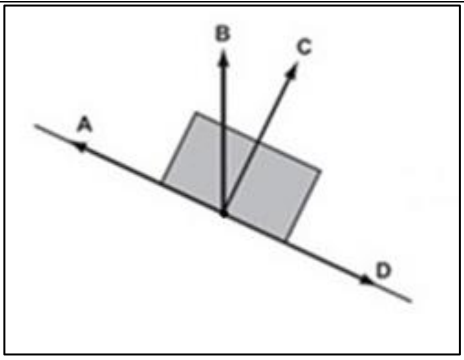
Item (Question) in brief (Item N10)	**Option**			**Percentage of students who selected the option**
Directions of the dynamic friction and the force of gravity acting on the block?		Direction of the force of dynamic friction	Direction of the force of gravity	
	(1)	Upwards parallel to the slope	Downwards perpendicular to the slope	29.03
	(2)	Upwards parallel to the slope	Downwards parallel to the slope	32.26
	(3)	Downwards parallel to the slope	Vertically downwards	30.65*
	(4)	Downwards parallel to the slope	Normal to and towards the slope	8.06

*(3) is the correct option

Table 7 shows that the percentage of students who selected options (1), (2) and (4), is nearly 70%. This means that 70% of the students do not know that the weight of an object always acts vertically downwards. Further nearly 60% of the students have selected options (1) and (2), meaning 60% of the students do not know that the frictional force acts in the opposite direction to that of the external force.

Item N11 tests whether the student knows that the normal reaction acts perpendicular to the surface on which it presses, outwards to the surface. Only around 34% of the students answered correctly to item N11. Table 8 shows how the students selected the options.

Table 8: Selection of options by the students for item N11

<table>
<tr><th>Item (Question) in brief
(Item N11)</th><th>Option</th><th>Percentage of students who selected the option</th></tr>
<tr><td rowspan="4">

Normal reaction on the block by the table?</td><td>(1) A</td><td>10.77</td></tr>
<tr><td>(2) B</td><td>27.69</td></tr>
<tr><td>(3) C</td><td>35.38*</td></tr>
<tr><td>(4) D</td><td>26.15</td></tr>
</table>

*Option (3) is the correct option.

Table 7 shows that the percentage of students who correctly answered item N11 is only around 35%. This shows that the majority of the students do not even have an idea of what the term 'normal reaction' means.

Item E6 tests whether the students know how the forces act on an object (wooden block) placed on a rough inclined plane (the block is in equilibrium). This item is an extension of items N10 and N11 where the student needs to know that (1) the weight of the block acts vertically downwards, (2) friction acts in the opposite direction to the direction that the block tends to move, and (3) the normal reaction on the block acts perpendicular to the inclined plane in an outward direction to the inclined plane. Only around 18% of the students were able to provide the correct answer. This is obvious when considering their low performance for the items N10 and N11, where N10 tests the first two conditions and N11 tests the third one.

When looking at the existing curriculum materials it was noticed that marking forces on an object placed on an inclined has not been given proper attention. Also, free body force diagrams are not introduced though the diagrams on which the forces are marked are discussed. Also, it is noted that nowhere it has been emphasized that the weight of an object acts vertically downward. Further nowhere in the existing Grades 10 and 11 Science curriculum, vector resolution or force resolution has been discussed. Therefore, the following suggestions are given to upgrade the existing curriculum materials by introducing clearly explained diagrams.

4.4.1 Suggestions to overcome the difficulties (found in items N10, N11, N12 and E6)

- Emphasizing that the weight of an object always acts vertically downwards at the end of Newton's second law of motion
- Introducing force resolution.
- Introducing the concept of normal reaction considering an object placed on a flat surface as well as on an inclined plane.
- Emphasizing how the normal reaction changes with the angle of the inclined plane by using force resolution.

- Introducing free body force diagrams to Grade 10 students before introducing them to Newton's third law of motion, Friction and Equilibrium of forces.
- Discussing marking the frictional force on an object moving on an inclined plane and an object kept at equilibrium on an inclined plane.
- Marking forces acting on an object at force equilibrium using free body force diagrams considering an object (wooden block) kept,
  - on a flat horizontal surface
  - on a rough inclined plane
- Considering an instance like a wooden block placed on a horizontal flat surface, emphasizing the need of distinguishing action and reaction pair of forces and the forces affecting the equilibrium of the block (Figure 6).

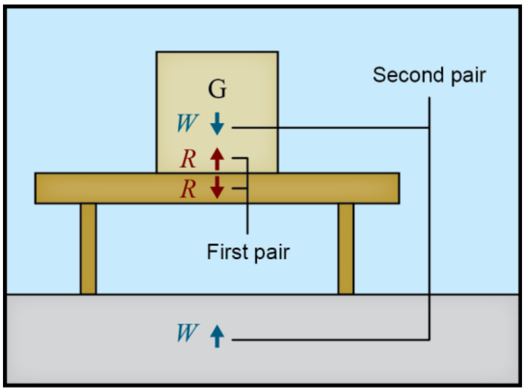


Figure 6: Action and reaction pairs of forces

In the first pair (Figure 6), a compressive force acts on the table downwards by the wooden block (action force). According to Newton's third law of motion, a force equal in magnitude acts in an upward direction on the wooden block. This second force is called 'normal reaction'. These two forces are equal in magnitude and opposite in direction and marked as *R*.

In the second pair (Figure 6), the weight of the block *W* acts vertically downwards from its centre of gravity G. According to Newton's third law, another force *W* should be there which is equal to the first force in magnitude and opposite in direction. It is said that the second force acts at the centre of the Earth.

Figure 7 is a free-body force diagram showing the first pair of forces and Figure 8 is a free-body force diagram showing the forces acting on the block when its equilibrium is considered. The teacher is supposed to emphasize the difference between the interpretations of the two diagrams.

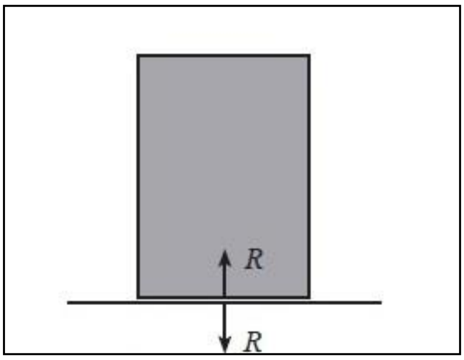


Figure 7: Free body force diagram showing
an action and reaction pair of forces

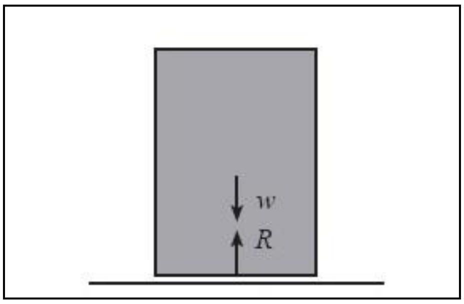


Figure 8: Free body force diagram showing the
forces under which the block is in equilibrium

5. Conclusion and Recommendations

This study is an exercise of identifying secondary school students' possible difficulties/ misconceptions in interpreting certain standard representations widely used in selected four physics-related science lessons, Resultant force, Newton's laws of motion, Friction, and Equilibrium of forces for Grade 10. A lesson-specific assessment tool capable of tracing the students' difficulties with the representations has been developed, validated, and administered to a sample of 72 Grade 11 students who had completed the lessons in their routine school schedule. It showed high reliability (Cronbach's alpha value of 0.795). The mean score for the assessment tool was 52.65% with a standard deviation of 24.94%, which is quite high for a standard deviation. Then a further analysis of students' performance for individual test items of the assessment tool was carried out and it revealed the following major difficulties/ misconceptions.

1) Inability to determine the line of action of a force acting on an object and hence not being able to determine whether two forces acting on the object are collinear, parallel, or inclined.
2) Not being aware of the term 'smooth surface' and its effect on the motion of an object on that surface.
3) Inability to convince the fact that applying a constant force continuously to an object (placed on a flat horizontal surface) results in the object travels with a uniform acceleration if the force exceeds the limiting friction.

4) Inability to convince the fact that a sudden release of the above-mentioned constant and continuously applied force which had been acting on this moving object results in the object to travel in uniform deceleration provided the travelling surface were uniformly rough, and the object to travel with uniform velocity (with the velocity it had gained when releasing the force) provided the travelling surface were smooth.
5) Inability to understand that two objects with different masses placed at the same height from the Earth reach the Earth at the same time, when they were to be simultaneously released from rest if the air resistance acting on them were made negligible.
6) Not being aware of the action force and reaction force mentioned in Newton's third law of motion act on two distinct objects.
7) Inability to distinguish between the forces under which an object (wooden block) placed on a flat horizontal surface maintains its equilibrium and, the action and reaction pair of forces (the compressive force by the block acting on the surface and the normal reaction force on the block by the table) as two different cases.
8) Difficulties in convincing that the weight of an object always acts vertically downwards irrespective of its positioning in the space.
9) Difficulties in understanding that the normal reaction on an object acts perpendicular to the surface and outwards the surface on which it is placed.
10) Difficulties in understanding that the friction force acts on an object in the opposite direction to the motion or in the direction the object tends to move.

The existing Grade 10 Science textbook contains a lot of activities. However, the above-mentioned learning difficulties/ misconceptions have not been adequately addressed in the book. Therefore, it is suggested that the new approach discussed herein be incorporated as much as possible within the school resources. The teachers are advised to send the significant changes to curriculum developers for them to incorporate such changes in their next round of revision.

A certain revision exercises are needed with going back earlier grades especially before introducing the resultant force as most of the students were not sufficiently familiar in their day-to-day life with the line of action of a force. Further, it is suggested to include the following areas in the new Grades 10 Science syllabus and the textbook/ module which are not currently included.

1) Free-body force diagrams;
2) Vector resolution and force resolution.

Teachers need not limit themselves to the representation modes emphasized in this article and they are at liberty to test other modes of representations and make suitable adjustments to their own assessment tools. It would do well for the teachers not to mix up these assessment tools with the traditional term or monthly tests usually held in the school.

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Conflict of Interest Statement
The authors declare no conflicts of interest.

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