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Development and Validation of Force Test to Assess Physics Education Students' Representational Competence

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Abstract. Force is one the physics cocncepts which is challenging for students. Several tests have been developed to measure students' understanding about force. However, the instruments for assessing students' competence to represent force concepts in various formats are limited. This study aims to develop and validate a multiple-choice test to assess students' representational competence of force. Research and development research is implemented in producing the test. The test includes three representations: graphs, equations, and words or descriptions which covers two contexts: on horizontal surface and on inclined plane. Moreover, this test involves three different situations namely an object is at rest, moving with constant velocity, and moving with constant acceleration. Each representation consists of 10 items and the total of items is 30. This test is administered to 51 undergraduate physics education students. The results show that the range of item difficulty index is 0.07-0.64 and discrimantory power is from 0.14 to 1.00. The reliability index for representational competence test of force to be 0.80 which is sufficiently high measurement. These results suggest that couple items of the test need to be revised before administering to the large sample.
Keywords: representations, competence, force, physics, test development

Introduction

Natural phenomena are studied by sciences like physics, chemistry, and biology, yet some of the notions are abstract and even complicated, thus they must be defined in terms of a more concrete form (Ainsworth, et al., 2011). For instance, interactions between organisms in certain environments can be visualized in sketches or schematic forms to facilitate the interaction (Won, et al., 2014); the speed of a car could be described by using a graph to make it easier to see changes in velocity (Sirait, 2020); the intermolecular interactions in a substance could be visualized as a structural diagram molecule to assist in visualizing abstract interactions (Treagust, et al., 2003). In addition to science topics, mathematical concepts like fractions can be explained in a variety of ways, including verbally, visually, numerically, graphically, ratio, percentage, and others (Ainley, et al., 2001). The term "representation" applies to them. Therefore, something that represents objects or processes is considered to be a representation (van Heuvelen, 1991).

The visual representations used in physics constitute as words or descriptions, drawings or sketches, tables, graphs, diagrams, etc. (de Cock, 2012; van Heuvelen & Zou, 2001). A concept of physics or problem could be displayed or visualized starting from real objects to abstract representations (Ainsworth, 1999; van Heuvelen & Zou, 2001). For example, an object at rest on a table could be displayed in the form of descriptions, sketches, force diagrams, and mathematical equations. Furthermore, the equation is the most frequently used representation in mathematics and physics, where this type of representation is often used to calculate the final answer.

Experts and students alike frequently employ representation to understand concepts, work through issues, and share scientific ideas. Representation competence, representation consistency, or representation proficiency refers to the capacity to use, produce, interpret, and transition from one kind of representation to another (Gebre & Polman, 2016; Kohl & Finkelstein, 2005; Kozma & Russell, 1997; Rau, 2017). Meta-representational competence was coined by DiSessa & Sherin (2000) and is defined as the capacity to select, create, and employ representations productively as well as the capacity to alter and create new representations.

Students may find it easier to solve problems if they have the ability to choose, employ, and even design appropriate representations. As an illustration of static electricity, consider the following: "A positive electric charge +q is at a distance d from point P. A charged electricity of +q is added to the left at a distance d from the first electric charge. Define the electric force's strength both before and after the addition of the electric charge. Some students might create a sketch to depict the difficulty and add vocal descriptions to finish it. To calculate the strength of the electric force, students will have the option of using a mathematical method or drawing force lines or force vectors. Concept comprehension also supports the choice between various representations. Students will become more adept at a concept when they can transform it from one form to another (Anggraini, et al., 2022).

Conceptual and perceptual representation competences are two categories for representation competence that are based on cognitive theory (Rau, 2017). A conceptual representation competency is the knowledge and ability to use representations and to choose particular representations to solve problems. The capacity to understand the meaning of a representation in order to process information and modify representations is known as perceptual representation competency. In order to generate and analyze the relationship between a reference, a representation, and its meaning, Peirce characterized competence representation as triadic meaning-making (Scheid, et al., 2019). An object, a procedure, or an event can all be references. Then, references might be portrayed through words, images, math, and other techniques. A concept, an idea, an explanation, etc. may be used to create meaning through interpretation. In physics, a box on a table serves as an example of a real item (reference), and arrows can be used to depict forces (force diagram representation), and they will signify the force that the earth and the table are exerting on the box.

One of the most important concepts in physics is force, as this concept is discussed in mechanics and static electricity (Nie, et al., 2019). An interaction between two items is what is referred to as a force (Etkina, et al., 2019). Take a book on a table as an example. In this scenario, there is interaction between the book and the table, the book and the earth, as well as others. Newton's Law is the basic law used to understand the concept of force experimentally and mathematically. The idea of force could be used to study how objects move (Robertson, et al., 2021). Previous studies showed that academics were interested in examining pupils' comprehension of force (McDermott & Reddish, 1999).

Several tests have been devised to gauge pupils' grasp of the notion of force. The force concept inventory (FCI), which consists of 30 test items, was the first of its kind in physics education (Hestenes, et al., 1992). This test, which consists of multiple-choice questions, is primarily designed to gauge students' knowledge of force and discussions of Newton's Laws. In physics education research, FCI has been widely employed as a test diagnostic. But for this test, a new circumstance or environment must be developed. Second, the force and motion concept evaluation (FMCE) discusses dynamics (movement and force) and kinematics (motion) (Thornton & Sokoloff, 1998). The 43 items in the FMCE have a variety of contexts, such as trains, inclined planes, and force charts. Students are required to respond to each question where there may be more than one possible answer in each context, which gives a number of options. This test is helpful for determining how well pupils comprehend force. Third, a multiple choice test adapted from the FCI called the representative force concept inventory (RFCI) focuses on four force concepts: gravity, Newton's laws I, II, and III (Nieminen, et al., 2010). The nine FCI questions are created in each of the three file types: motion maps, vectors, and graphics, for a total of 27 questions. Only 168 students were engaged in the study, which limits the test's statistical validity and raises concerns about its reliability. The counterintuitive dynamics test (CIDT) (Balta & Erylmaz, 2017) is the newest force-related test. The first, second, and third laws of Newton are three of the principles covered by the test. 30 questions with three options make up the CIDT. The problems include the drawings and sketches. While the students must comprehend the ideas and mathematical formulae, diagrams and equations are not part of the test.

The notion of force is covered by the tests that have been created, but it has not been addressed whether students can fully comprehend a concept when it is represented by explanations, diagrams, or mathematical equations. The experts advised students to understand concepts, work out challenges, and explain ideas through representation. Therefore, a standardized test that accurately assesses students' comprehension of force in a variety of circumstances and formats must be created. The application of Newton's Law to numerous situations, including inclined planes and horizontal surfaces, will be covered on this test. An object at rest and the one in motion are the two conditions that make up every context. Every circumstance consists of three questions, which are presented in a variety of ways, such as diagrams, equations, and explanations. In order to create a representational competence based on reliable and valid force concepts, this research's goal is to develop those concepts. It is anticipated that this test will be a benchmark assessment that may be used to gauge students' grasp of the idea of force.

Method

Fifty-one (51) first-year students from Tanjungpura University's physics education study program, consisting of 9 men and 42 women, participated in this study. The students are prepared to pursue careers as junior high and senior high school physics teachers. They acquire pedagogy content knowledge in addition to learning the subject of physics (Etkina, 2010; Schiering, et al., 2022). When collecting the samples, a purposive sampling technique will be used (Creswell & Creswell, 2018), and the students will have recently studied the idea of force in a course on fundamental physics. The force representational competence test is created using developmental research. Incorporating define, create, develop, and disseminate into the model is 4D (Thiagarajan, 1974).

Define.
At this point, the material, concepts, competencies, and indicators that were used to create the test are being examined.

Design. At this stage what is done is to write questions by determining the number of items, the form of questions, and the form of representation. For more details, a test design is presented in Table 1.

Table 1. Test structure and design

Concept	Context	Situation	Representation
Newton's First and Second laws	Horizontal surface and inclined plane	At rest and moving state	Diagrams, mathematical equations, and description

Develop. In order to determine whether the prepared questions are appropriate given the indicators and concepts (validation content), some experts, in this case physics education lecturers, validate the questions (Matejak, et al., 2022). The test was subsequently completed after taking into account the experts' comments and suggestions. A few students were also given test drafts to review to see if the questions were readable. 51 physics education students who had studied Newton's Law in the introductory course were then given the amended tes. Students needed 45 minutes to compete the test. The student responses were then gathered for study. In order to produce a valid representation competency test, the aspects to be analyzed cover the validity, reliability index, difficulty index, and differentiability (Ding & Beichner, 2009; Rainey, et al., 2022; Wulandari, et al., 2022). The index or expected value of each aspect is shown in Table 2.

Table 2. Analysis of the test

Analysis	Possible Value	Possible Value
Difficulty Index	[0, 1]	≥ 0,3
Discriminatory Index	[-1, 1]	≥ 0,3
Reliability Index	[0, 1]	≥ 0,7

Results and Discussion

This research is still in the preliminary stage (pilot study) (Ceuppens, et al., 2018; Rainey, et al., 2022) to produce a FRCT through several stages including define, design, and develop.

Define Stage

What is done at the define stage is to determine the material or concept as well as to develop test indicators. The concept chosen is the concept of force on Newton's Law because this concept is very important for students to learn other physics concept (Robertson, et al., 2021). The form of representation developed in the test include diagrams, mathematical equations, and descriptions (Scheid, et al., 2019) while the indicators include determination of force diagrams for objects at rest and in motion with constant velocity and constant acceleration, determine the mathematical equations right from the diagram that has been selected, and determine the forces acting on the rest and moving object with constant veocity and constant acceleration. For a more complete information of the question indicators are presented in Table 3.

Table 3. Forms of representation and indicators of the test

Representation	Indicators
Force Diagram	• Determine the appropriate force diagram for an object at rest • Determine the appropriate force diagram for the object being pulled with F Force. • Determine force diagram for an object moving with constant velocity • Determine the appropriate force diagram for an object moving with constant acceleration
Mathematical Equation	• Determine the mathematical equation of the selected force diagram for stationary objects • Determine the mathematical equation of the selected force diagram for an object moving at a constant velocity • Determine the mathematical equation of the selected force diagram for an object moving with constant acceleration
Description	• Identify the forces acting on a stationary object • Identify the forces acting on a moving object at a constant velocity • Identify the forces acting on a moving object with constant acceleration

Design Stage

This stage determines the form of the test, namely a multiple-choice, to be then followed by determining the number of items. Each representation (diagrams, mathematical equations, and description) consists of 10 items making the total is 30 items. The context of the question consists of a horizontal surface and an inclined plane. Then the situation of objects in the problem is in a state of rest and motion. The distribution of questions is presented in Table 4.

Table 4. Questions distribution

Representation	Questions			
	Horizontal		Inclined plane	
	At rest	Moving	At rest	Moving
Force diagrams	1,4,7	10,13	16,25	19,22,28
Mathematical equation	2,5,8	11,14	17,26	20,23,29
Description	3,6,9	12,15	18,27	21,24,30

Examples of item questions (10,11,12) for a traveling object across a horizontal surface with a constant velocity, like that depicted in Figure 1, are in the form of diagrams, mathematical formulae, and verbal inquiries. Respondents are requested to select a diagram in response to the provided scenario in which a block is being pushed by a F force moving at a constant pace across a table in point no. 10. Then, in item number 11, from the diagram that was chosen in item number 10, students must select the suitable mathematical equation. The next step is to decide which of the statements about the forces on the beam that cause it to move at a constant velocity is true.

Develop Stage

This development stage includes testing of the validity, level of difficulty, discriminating power, and reliability. In this case the validity being tested is content validity, namely the judgment of the expert (Balta, et al., 2022). As many as three physics education lecturers are to be involved as the validators to assess the suitability of each item with indicators, suitability of the concept of physics, the suitability of the questions with the three forms of representation, and the respective answers. From the results of expert assessments related to indicators, 9 out of 10 indicators are in accordance with the item questions. The validator suggests to combine the indicator, namely "determining the appropriate force diagram for an object being pulled by an F force” with another indicator or other indicators because even if an object is being pulled by an F force, the object can remain still, move at a constant velocity, and have a constant acceleration.

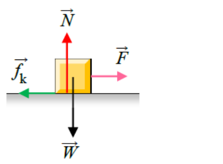
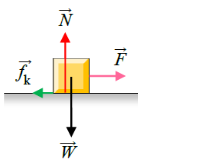
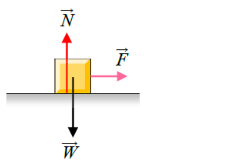
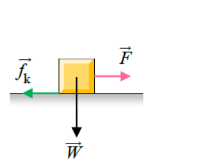
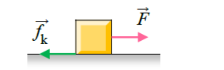
Situasi 4 Sebuah balok ditarik dengan gaya $\vec{F}$ bergerak dengan kecepatan konstan di atas meja (permukaan datar).				
10. Diagram mana di bawah ini yang menunjukkan gaya-gaya yang bekerja pada balok				
A	B	C	D	E
				
11. Tentukanlah persamaan matematis yang menunjukkan besar gaya F berdasarkan diagram gaya yang telah anda pilih				
A	B	C	D	E
$\Sigma \vec{F}_x = ma$ $F = ma$	$\Sigma \vec{F}_x = ma$ $N - W = ma$	$\Sigma \vec{F}_x = ma$ $F + N - f_k - W = ma$	$\Sigma \vec{F}_x = 0$ $F - f_k - W = 0$	$\Sigma \vec{F}_x = 0$ $F - f_k = 0$
12. Pernyataan yang tepat menyebabkan balok bergerak dengan kecepatan konstan A. Besar gaya F lebih besar dari gaya gesek B. Besar gaya F sama dengan besar gaya gesek C. Besar gaya F lebih kecil dari gaya gesek D. Besar gaya F sama dengan besar gaya normal ditambah gaya berat E. Besar gaya F sama dengan massa kali kecepatan				

Figure 1. The example of questions in three diffrent form of representations: diagrams, mathematical equations, and descriptions

Furthermore, with regard to the concept of physics, all items are already in accordance with the concept Newton's First and Second Laws. Then, relating to the form of representation shown in the problem, the validators provide some inputs for being careful in drawing the short length of the arrow as a representation of the force vector because it will affect the selection of mathematical equations. The color of the arrows made for each type of force is made differently (black for gravity, red for normal force, blue for static friction, green for kinetic friction force, and pink for (F) force to make it easier for students to identify forces and minimize student errors in seeing the vector of force. The ability that one must possess to understand the concept of force, especially with regard to diagrams, is vectors (Sirait, et al., 2017). Apart from that, the experts also suggest that mathematical equations be presented more concisely so that each mathematical representation only be made two equations. Mathematical equations are a form of representation that is most often used in studying the concepts of physics and being one of the challenges for students (Sirait, et al., 2018).

Then the validator also checks the answers to each item. There are several inputs among others that the choices of answers should be tiered with regard to the force diagram starting from the force on the x-axis then on the y-axis (item number 2). Then the order of force types (item no. 6), should begin from normal force and so on while for the numbers 7, 10, and 13 (diagram form questions), one validator highlighted two choices of answers that are almost the same. For question number 9, the answers of D and E are almost the same for the reason that the length of the normal vector force is almost the same. Therefore, the length of the normal vector force arrow should be made more contrastive. The same is true for numbers 10 and 13, namely the length of kinetic vector force friction. The choice of answer to number 18 (descriptive form), the option C is corrected so as to read "the component of the weight in the direction of the inclined plane is equal to the frictional force". Finally, the choice of answer to number 27 (descriptive form) option E is corrected so as to read "The amount of (F) force is equal to the magnitude of the frictional force plus the component of the weight in the direction of the inclined plane ".

The assessment and input from the experts become substances for improving the force representational competence test. After all items have been revised, it was then retested to three students to find out the legibility of the questions and also the time spent to read and select the answers. The results obtained are that each question is self-explanatory. The time spent doing it is between 30 to 45 minutes. So it was decided that the time to do this test to be 45 minutes. Each of these force representational competency test items does not stand alone, meaning that each situation consists of 3 items in different forms (diagrams, mathematical equations, and description) are related to each other. The optional answers to mathematical equations are obtained from the answers available in the diagram. Then, to answer the questions in the descriptive forms, the answers from diagrams and mathematical equations are to be used.

In furtherance to that, the test was then given to 51 of first year physics education students on a pilot study to collect useful data for test analysis. To identify the test items that need to be modified or eliminated, pilot studies are crucial (Balta & Logman, 2022). The notion of force was taught to students in a basic physics course. After the data was gathered, it was discovered that every student responded to every question, and no one (as long as they chose) selected the same response for every question, allowing for the analysis of every student response to determine the level of difficulty, discriminatory power, and reliability.

Table 5. Statistical Analysis

Diagram			Mathematical equation			Description		
Item	Item difficulty	Discrimination index	Item	Item difficulty	Discrimination index	Item	Item difficulty	Discrimination index
1	0,44	0,28	2	0,40	0,28	3	0,64	0,35
4	0,32	0,42	5	0,28	0,71	6	0,32	0,42
7	0,20	0,21	8	0,24	0,57	9	0,28	0,57
10	0,20	0,14	11	0,12	0,14	12	0,12	0,14
13	0,16	0,42	14	0,40	0,57	15	0,40	1,00
16	0,28	0,72	17	0,20	0,14	18	0,40	0,57
19	0,32	0,42	20	0,07	0,14	21	0,28	0,71
22	0,24	0,28	23	0,28	0,35	24	0,32	0,71
25	0,50	0,85	26	0,35	0,42	27	0,52	0,71
28	0,44	0,28	29	0,24	0,28	30	0,48	0,71

Based on the results of statistical analysis, it was found that the index of difficulty for this test ranged from 0.07 to 0.64. The index of difficulty for each item is shown in Table 5. Expected difficulty index for this test is $\geq 0{,}3$. The higher item difficulty index indicates that the item is easier and vice versa the index value is lower shows that the problem is more difficult (McCowan, 1999). There are up to 5 items in the difficult category and 5 items in the medium category for the diagram format question. The percentage of items in the intermediate and challenging categories is equal for diagram representation. Then there are 7 items in the "difficult" category and 3 items in the "medium" category related to mathematics form. However, there are 3 items in the tough category and 7 items in the medium category when it comes to the topic of description form and the opposite to the form of mathematical questions. It is necessary to have items in the difficult category for this test considering this test measuring specific abilities, namely representation competence (Ceuppens, et al., 2018). Besides that, the ability of mathematical representation and description comes from diagrammatic problems; in other words, the matter of mathematical representation and description does not stand alone.

According to the difficulty index, items 10 through 12 (Figure 1), each with a difficulty index of 0.20, 0.12, and 0.12 where this value is unexpected, are consistent with the difficult group. Up to 12 participants correctly identified option A for item number 10, which states that the length of the vector force (F) is equal to the length of the vector force kinetic friction (f_k). While 13 people chose option C, which is merely the F force operating on the horizontal surface, and 11 people chose option B, which states that the length of the vector force F is longer than the length of the vector force friction. Table 6 displays the distribution of students' answers (the bold number is the right answer). Then, for question math question (number 11), utilizing Newton's Second Law equation and adding up all forces both horizontally and vertically, 18 respondents chose option C. 13 participants selected option A, which corresponds to Newton's Second Law of equality and choice C in the diagram problem. Option E, which employs the Newton's First Law equation, is the correct response to the given mathematical problem. The majority of students selected choice A for the description question (number 12), which is incorrect because it states that the larger F force is greater than the frictional force. Despite the fact that all three of these questions are rated as challenging, fewer pupils than those who correctly answered the diagram questions were able to solve the mathematical problems. This makes sense since if the diagram is incorrect, pupils cannot provide accurate answers to mathematical queries. These three points need to be altered because they fall within the unfavorable group when measured by their ability to differentiate.

Table 6. Distribution of answers

Diagram						Mathematical equation						Description					
Item	A	B	C	D	E	Item	A	B	C	D	E	Item	A	B	C	D	E
1	26	**19**	3	2	1	2	9	3	14	**16**	9	3	6	5	11	7	**22**
4	3	6	**18**	16	8	5	**13**	5	5	18	10	6	**17**	7	7	18	10
7	10	6	9	**8**	18	8	12	**10**	19	10	0	9	6	21	**15**	6	3
10	**12**	11	13	9	6	11	13	8	18	4	**8**	12	20	**9**	6	7	9
13	10	15	9	11	**6**	14	5	12	**15**	10	9	15	8	9	4	**20**	10
16	8	7	5	**18**	13	17	7	**13**	6	13	12	18	8	11	**16**	13	3
19	**14**	9	14	2	12	20	14	8	16	9	**4**	21	12	**12**	7	12	8
22	4	6	17	12	**12**	23	12	17	**14**	5	3	24	8	10	11	**15**	7
25	14	**9**	12	8	7	26	12	13	11	**10**	5	27	6	8	8	7	**22**
28	2	7	**16**	13	13	29	**8**	16	12	12	3	30	**24**	4	9	6	8

Items no. 10, 11, and 12 are relatively difficult for students to be influenced by several things including: student inaccuracy in applying the concept to analyze the situation, in this case an object moving at a constant speed. Students tend to think that when an object moves, the force vector F is bigger from the friction force vector. Students often experience misconceptions in this section, namely unable to distinguish the resultant force for an object moving with constant velocity and objects moving with constant acceleration (Nie, et al., 2019). The thing that the second is that students tend to think that when an object moves, the mathematical equation used is Newton's Second Law. Nie, et al. (2019) states that students need to be taught how to integrate the concept of force and motion. The third is a force vector, which is just used to identify the force and is not utilized to convey the force's magnitude (Sirait, 2020). According to Rau (2017), the representational competence is the capacity for information extraction from a representation. Students are expected to be able to describe the diagrammatic representation and respond to inquiries regarding its mathematical representation in this situation (force vector).

This is not the same as the scenario where an object is moving at a constant rate of acceleration (points 13, 14, and 15). Only six persons can correctly select the diagram (option E), meaning that the force vector F is longer than the force vector resulting from kinetic friction. While 20 respondents select the greater F force of the frictional force for a block with constant acceleration, 15 people select the correct mathematical equation. Inconsistent learners may overlook the force vector's short length and the potential for memorization of the equation for Newton's second law while successfully responding to diagrammatic, mathematical, and descriptive questions. This is evident from the mathematical decision, which is the simultaneous addition of the forces acting in the horizontal and vertical axes. This is consistent with the findings of Sirait, et al. (2018) research, which found that pupils have trouble understanding the idea of force and have limited vector abilities. These three things were rated as good despite the fact that the students' answers varied. This is due to their strong discriminatory power.

According to the discriminating power for all item questions, the levels for questions 10, 11, and 12 are quite low, falling below 20% (0.14). This proves that just 14% of students can be classified into the top and lowest group using these three criteria, because those three need to be revised. Consequently, the reliability index of force representational competency test is 0.80. This result is as expected, namely $\alpha \geq 0{,}7$. Reliability is the extent to which the measurement results remain the same when repeated or the stability of the measurement. Cronbach's alpha coefficient was classified as excellent by Cohen, et al. (2018). Nevertheless, before being applied on a bigger scale, some questions still require revision.

Conclusion

A test developed as a result of this research is used to gauge how well pupils can convey the idea of force. This test contains of 30 questions, 10 of which are each of the three types of questions: diagrams, equations, and descriptions. The statistical analysis's findings demonstrate that the reliability coefficient falls into the good category. However, due to the extremely poor discriminating power and high index of difficulty, several items still need to be revised. Since this exam is currently in the early stage, further research and analysis are needed before it can be used on a broader scale to create standardized tests. The force representational competency test is one of the tools used by academics and educators to gauge students' comprehension of the notion of force in various forms of representation.

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References

Ainley, J., Pratt, D., & Nardi, E. 2001. Normalising: Children's activity to construct meanings for trend. *Educational Studies in Mathematics*, 45(1–3):131–146. https://www.jstor.org/stable/3483099.

Ainsworth, S. 1999. The functions of multiple representations. *Computers & Education*, 33(2–3):131-152. https://doi.org/10.1016/S0360-1315(99)00029-9.

Ainsworth, S., Prain, V., & Tytler, R. 2011. Drawing to learn in science. *Science*, 333(6046):1096-1097. https://doi.org/10.1126/science.1204153.

Anggraini, M., Huda, I., Safrida, S., Rahmatan, H., & Djufri, D. 2022. Penerapan model multiple representation berbasis somatis, auditory, visual, intelektual terhadap self efficacy peserta didik. *Jurnal Pendidikan Sains Indonesia (Indonesian Journal of Science Education)*, 10(1):11–20. https://doi.org/10.24815/jpsi.v10i1.21690.

Balta, N. & Eryılmaz, A. 2017. Counterintuitive dynamics test. *International Journal of Science and Mathematics Education*, 15(3):411-431. https://doi.org/10.1007/s10763-015-9694-6.

Balta, N., Japashov, N., Salibašić Glamočić, D., & Mešić, V. 2022. Development of the High School wave optics test. *Journal of Turkish Science Education*, 19(1):306-331. https://doi.org/10.36681/tused.2022.123.

Balta, N. & Logman, P.S.W.M. 2022. Development of counterintuitive basic electric dc circuits test. *Physics Education*, 57(4):045033. https://doi.org/10.1088/1361-6552/ac61ef.

Ceuppens, S., Deprez, J., Dehaene, W., & de Cock, M. 2018. Design and validation of a test for representational fluency of 9th grade students in physics and mathematics: The case of linear functions. *Physical Review Physics Education Research*, 14(2):1-19. https://doi.org/10.1103/PhysRevPhysEducRes.14.020105.

Cohen, L., Manion, L., & MOrrison, K. 2018. *Research Methods in Education,* 8th edition*,* Routledge, Taylor & Francis Group, London.

Creswell, J.W. & Creswell, J.D. 2018. Research Design: *Qualitative, Quantitative & Mixed Methods Approaches*, 5th edition, SAGE Publication, London.

De Cock, M. 2012. Representation use and strategy choice in physics problem solving. *Physical Review Special Topics-Physics Education Research*, 8(020117):1-15. https://doi.org/10.1103/PhysRevSTPER.8.020117.

Ding, L. & Beichner, R. 2009. Approaches to data analysis of multiple-choice questions. *Physical Review Special Topics-Physics Education Research*, 5(020103):1-17. https://doi.org/10.1103/PhysRevSTPER.5.020103.

Disessa, A.A. & Sherin, B.L. 2000. Meta-representation: an introduction. *Journal of Mathematical Behaviour*, 19(4):385-398. https://doi.org/10.1016/S0732-3123(01)-00051-7.

Etkina, E. 2010. Pedagogical content knowledge and preparation of high school physics teachers. *Physical Review Special Topics-Physics Education Research*, 6(020110):1–26. https://doi.org/ 10.1103/PhysRevSTPER.6.020110.

Etkina, E., Planinsic, A., & van Heuvelen, A. 2019. *A College Physics: Explore and Apply*, 2nd edition, Pearson, New York.

Gebre, E.H. & Polman, J.L. 2016. Developing young adults' representational competence through infographic-based science news reporting. *International Journal of Science Education*, 38(18):2667-2687. https://doi.org/10.1080/09500693.2016.1258129.

Hestenes, D., Wells, M., & Swackhamer, G. 1992. Force concept inventory. *The Physics Teacher*, 30(3):141-158. https://doi.org/10.1119/1.2343497.

Kohl, P.B. & Finkelstein, N.D. 2005. Student representational competence and self-assessment when solving physics problems. *Physical Review Special Topics-Physics Education Research*, 1(010104):1-11. https://doi.org/10.1103/PhysRevSTPER.1.010104.

Kozma, R.B. & Russell, J. 1997. Multimedia and understanding: Expert and novice responses to different representations of chemical phenomena. *Journal of Research in Science Teaching*, 34(9):949-968. https://doi.org/10.1002/(SICI)1098-2736(199711)34:9<949::AID-TEA7>3.0.CO;2-U.

Maryani, I., Prasetyo, Z.K., Wilujeng, I., Purwanti, S., & Fitrianawati, M. 2021. HOTs multiple choice and essay questions: a validated instrument to measure higher-order thinking skills of prospective teachers. *Turkish Journal of Science Education*, 18(020116):674–690. https://doi.org/10.36681/tused.2021.97.

Matejak Cvenic, K., Planinic, M., Susac, A., Ivanjek, L., Jelicic, K., & Hopf, M. 2022. Development and validation of the conceptual survey on wave optics. *Physical Review Physics Education Research*, 18(010103):1-11. https://doi.org/10.1103/ PhysRev-PhysEducRes.18.010103.

McDermott, L.C. & Redish, E.F. 1999. Resource letter: PER-1: physics education research. *American Journal of Physics*, 67(9):755-767. https://doi.org/10.1119/1.19122.

Nie, Y., Xiao, Y., Fritchman, J.C., Liu, Q., Han, J., Xiong, J., & Bao, L. 2019. Teaching towards knowledge integration in learning force and motion. *International Journal of Science Education*, 41(16):2271-2295. https://doi.org/10.1080/09500693.2019.1672905.

Nieminen, P., Savinainen, A., & Viiri, J. 2010. Force concept inventory-based multiple-choice test for investigating students' representational consistency. *Physical Review Special Topics-Physics Education Research*, 6(020109):1-12. https://doi.org/10.1103/PhysRevSTPER.6.020109.

Rainey, K.D., Vignal, M., & Wilcox, B.R. 2022. Validation of a coupled, multiple response assessment for upper-division thermal physics. *Physical Review Physics Education Research*, 18(2):1–20. https://doi.org/10.1103/PhysRevPhysEducRes.18.020116.

Rau, M.A. 2017. Conditions for the effectiveness of multiple visual representations in enhancing STEM learning. *Educational Psychology Review*, 29(4):717-761. https://doi.org/10.1007/s10648-016-9365-3.

Robertson, A.D., Goodhew, L.M., Scherr, R.E., & Heron, P.R.L. 2021. University student conceptual resources for understanding forces. *Physical Review Physics Education Research*, 17(10121):1-18. https://doi.org/10.1103/PhysRevPhysEducRes.17.010121.

Scheid, J., Müller, A., Hettmannsperger, R., & Schnotz, W. 2019. Improving learners' representational coherence ability with experiment-related representational activity tasks. *Physical Review Physics Education Research*, 15(010142):1-23. https://doi.org/10.1103/PhysRevPhysEducRes.15.010142.

Schiering, D., Sorge, S., Keller, M.M., & Neumann, K. 2022. A proficiency model for pre-service physics teachers' pedagogical content knowledge (PCK)—What constitutes high-level PCK? *Journal of Research in Science Teaching*, 60(1):136–163. https://doi.org/10.1002/tea.21793.

Sirait, J., Hamdani, & Oktavianty, E. 2017. Analysis of pre-service physics teachers' understanding of vectors and forces. *Journal of Turkish Science Education*, 14(2):82-95. https://doi.org/ 10.12973/tused.10200a.

Sirait, J., Hamdani, & Mursyid, S. 2018. Students' understanding of forces: Force diagrams on horizontal and inclined plane. *Journal of Physics: Conference Series*, 997(012030):1-7. Htps://doi.org/10.1088/1742-6596/997/1/012030.

Sirait, J. 2020. Students' use of representations in solving physics problems: complete and incomplete force diagrams. *Disertasi*, University of Leicester, UK. https://doi.org/10.25392/leicester.data.13322732.v1.

Thornton, R.K. & Sokoloff, D.R. 1998. Assessing student learning of Newton's laws: The force and motion conceptual evaluation and the evaluation of active learning laboratory and lecture curricula. *American Journal of Physics*, 66(4):338-351. https://doi.org/10.1119/1.18863.

Treagust, D.F., Chittleborough, G., & Mamiala, T.L. 2003. The role of submicroscopic and symbolic representations in chemical explanations. *International Journal of Science Education*, 25(11):1353–1368. https://doi.org/10.1080/0950069032000070306.

Van Heuvelen, A. 1991. Overview, case study physics. *American Journal of Physics*, 59(10):898-907. https://doi.org/10.1119/1.16668.

Van Heuvelen, A. & Zou, X. 2001. Multiple representations of work–energy processes. *American Journal of Physics*, 69(2):181-194. https://doi.org/10.1119/1.1286662.

Won, M., Yoon, H., & Treagust, D.F. 2014. Students' learning strategies with multiple representations: explanations of the human breathing mechanism. *Science Education*, 98(5):840–866. https://doi.org/10.1002/sce.21128.

Wulandari, T., Ramli, M., & Muzzazinah, M. 2022. Analisis butir soal dynamic assessment untuk mengukur pemahaman konsep klasifikasi tumbuhan pada mahasiswa. *Jurnal Pendidikan Sains Indonesia (Indonesian Journal of Science Education)*, 10(1):191–201. https://doi.org/10.24815/jpsi.v10i1.