SENIOR HIGH SCHOOL STUDENTS' DIFFICULTIES IN SOLVING IMPULSE AND MOMENTUM PROBLEMS

A. M. Saifullah[1*], Sutopo[2], H. Wisodo[2]

[1]Postgraduate of Physics Education, Universitas Negeri Malang, Indonesia
[2]Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Malang, Indonesia

ABSTRACT

Impulse momentum theorem is one of the fundamental principles of physics, especially in mechanics. Therefore, students' understanding of impulse and momentum will contribute to their success in learning physics. This study exposed common students difficulties in solving problems related to impulse and momentum. The subjects consisted of 175 students of a Senior High School in Malang, 70 students of grade XI who recently learned about impulse and momentum and 105 students of grade XII who relearned the topic for national examination preparation. The data were gathered using multiple-choice test with open explanation and confidence rating scale. The study concluded that the students' difficulties were not only caused by their lack understanding of the concepts but also by their deficiency in using vectors.

INTRODUCTION

One of the important goals of learning physics is to facilitate students to grasp fundamental physics concepts and to apply them to solve related physics problems. However, to reach these aims is not as easy as one thinks. It is because students often have mistakenly formed conceptions when they come to physics lessons (Halim et al., 2014) or they have not understood the basic knowledge before they learn new concepts (Turányi & Tóth 2013). Many physics educators label such mistaken or contradicting thoughts as misconception (Lawson, 1995; Hammer, 1996; Chamber & Andre, 1997; Yalcin, 2008; Docktor & Mestre, 2014). Misconception is the leading cause of students' difficulties since it is hard to be changed (Sencar & Eryilmaz, 2004; Hung & Jonassen, 2006; Stylos et al., 2008; Docktor &

Mestre, 2014; Widarti et al., 2016) and it would interfere with students' construction of new knowledge (Osborne et al., 1983; Turányi & Tóth, 2013). On the other hand, physics consists of a hierarchy set of knowledge, so according to the theory of constructivism, understanding of the prerequisite knowledge is necessarily to comprehend new concepts. Therefore, when designing a physics lesson teachers need to be aware to students' misconceptions and the concepts that students tend to be difficult to understand.

Many studies have uncovered students misconceptions and difficulties in many branches of physics. In mechanics, for instance, most students face difficulties on one-dimensional motion (Trowbridge & McDermott, 1980; Trowbridge & McDermott, 1981; McDermott et al., 1987), Newton's law (Halloun & Hestenes, 1985; Thornton & Sokoloff, 1998; Brown, 1989; Demirci, 2008; Rosenblatt & Heckler, 2011; Elmehd et al., 2013), rotational dynamic (López, 2003; Ortiz, 2005; Oliveira, 2011), conservation of energy

*Alamat korespondensi:
E-mail: anisa.matinu@gmail.com

(Dalaklioğlu et al., 2015), and fluid mechanics (Besson, 2004; Loverude et al., 2010; Wijaya et al., 2016), mechanical wave propagation (Sutopo, 2016) and reflection (Kryjevskaia et al., 2011; Kryjevskaia et al., 2012). In thermodynamics, students tend to confuse temperature with heat (Gönen & Kocakaya, 2010; Alwan, 2011) and fail to apply state equation of ideal gas in problem solving (Kautz et al., 2005). In electricity, students' difficulties deal with electricity circuits (Stetetzer et al., 2013) and Ohm's law (Vreeland, 2002; Sencar & Eryilmaz, 2004). Those findings show that there are still many misconceptions and difficulties faced by students in many branches of physics. Furthermore, the abundance of research revealing common student difficulty suggests that information about students' misconception and difficulties is very important in physics education.

Newtonian mechanics is a branch of physics that underlies almost all other branches of physics. Thus, it is important for students to grasp concepts and principles in Newtonian mechanics. Students' success in mastering Newtonian mechanics determines their success in learning other branches of physics (Hestenes & Well, 1992). The basic law in Newtonian mechanics is Newton's laws of motion. However, students need to grasp robust understanding of its derived laws as well, i.e. work-energy theorem and impulse-momentum theorem.

One of derived laws in Newtonian mechanics is impulse-momentum theorem (Hestenes, 1987). This theorem is highly useful to solve mechanic problems which involve force acting over an interval of time or changing with time (Serway & Jewett, 2014). Therefore, in addition to Newton's laws of motion, students need to meaningfully understand the theorem of impulse and momentum.

Some researchers have revealed students difficulties about impulse and momentum. Lawson & McDermott (1987) and Pride et al. (1998) found students misconceptions about the relationship between impulse and momentum. Graham & Berry (1996) revealed that most of 17-18 years old students think of momentum as scalar quantity. Singh & Rosengrant (2003) and Close & Heron (2010) found that most university students also think of momentum as scalar. Other researchers found students difficulties in applying conservation of momentum on collision problems (Bryce & MacMillan, 2009). Students believed that the conservation of momentum hold for each colliding objects, not for the system consisting of those objects (Ivowi, 1986).

This article is aimed to expose common difficulties encountered by Indonesian students in solving problems related to the topics of impulse and momentum. The findings of this study are expected to provide new information about students' difficulties on impulse and momentum.

METHODS

This research was a descriptive study using a survey technique. The subjects of this research were 175 students of a public senior high school in Malang who had learned impulse and momentum. They consisted of 70 students of grade XI who recently learned about impulse and momentum and 105 students of grade XII who relearned the topic for national examination preparation.

The data were collected by using a test as an instrument to measure students' levels of conceptual understanding on the impulse and momentum concepts that were based on standard competence of such topic stipulated in the 2013 curriculum. This test was given in the form of reasoned multiple choice complemented by a confidence rating scale consisting of 12 questions, which include 2 questions about momentum change, 4 questions about impulse-momentum theorem, and 6 questions about momentum conservation. However, based on the reasons given by the students for their answers, there were only 4 questions from each subtopic that require a further study regarding their difficulties. Therefore, this article would only discuss those 4 questions. Some questions given in the test were resulted from the modification of some standardized tests, namely Force Concept Inventory (Hestenes et al., 1992) and Energy and Momentum Concept Survey (Singh & Rosengrant, 2003).

The data analysis was done based on the students' answers to the test of impulse and momentum concepts mastery. In each question, students were asked to choose one correct answer from the given multiple choices, write down the reasons for their answers, and determine their confidence level about the answers. The reasons were used to reveal the students' way of thinking in solving the problems related to impulse and momentum. The students' certainty level about their answers was measured by using a Likert scale ranging from 0 to 3. 0 meant very unsure (only guessing), 1 meant less sure/sure enough, and 3 meant extremely sure about the answer. The levels of students' understanding would be categorized based on their answers and their certainty levels. This analysis method that is also known as Certainty of Response Index (CRI) had been done by some researchers, e.g. Hasan et al. (1999)

and Potgieter et al. (2010). The method used for the analysis of students' understanding level in this research referred to the method employed by Sutopo (2016) who adapted the method utilized by Potgieter et al. (2010). Based on their answers, the levels of students understanding were grouped into 4 categories. First, students who answered correctly with a certainty level of 3 would be considered to have a good knowledge of the concepts. Second, students who answered correctly with a certainty level of 2 would be deemed to have enough understanding of the concepts. Third, students who answered correctly with certainty level 1 or 0, or students who answered incorrectly with a certainty level of 2, 1, or 0 would be considered to have a low understanding of the concepts. Lastly, students who answered incorrectly with a certainty level of 3 would be deemed to have misconceptions.
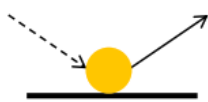
RESULTS AND DISCUSSION

Students' Difficulties in Solving Change of Momentum's Problems

Two questions illustrated in Figure 1a and 1b were used to identify the students' ability in solving change of momentum's problems. Both of the questions used the same principle of physics, but the contexts and representation forms were different. The question in figure 1a was presented in a mathematic-quantitative form in the context of one-dimensional motion in which a trolley changed its motion as a result of a collision with the wall. The question in figure 1b was presented in diagram and symbol in which a ball changes its motion in a collision with the floor. The distribution of students' answers and the level of students' understanding of the question in Figure 1a are completely presented in Table 1,

while the distribution of students' answers and the level of students' understanding of the question in Figure 1b are completely presented in Table 2.

Based on the reasons given by the students for their answers to the question in Figure 1a, it was shown that all students had understood that momentum was a vector identified as a result of the addition of an object's mass and its speed. Nevertheless, the students found difficulties in determining the change of momentum when the object changed its motion. Students' difficulties were encountered more frequently when they were trying to solve the question in Figure 1b than the question in Figure 1a. 54.29 % students answered the question presented in Figure 1a correctly (Table 1), whereas only 15.43 % students could respond to the question in Figure 1b correctly (Table 2). It showed that it is easier for the students to solve a question presented in a mathematic-quantitative form than the one presented in diagram and symbol forms (Torigoe, 2008; Docktor & Mestre, 2014).The detailed explanations on the students' difficulties in solving both questions are presented below. For the question in Figure 1a, although 95 students answered correctly, i.e. the option D, there were only 51 students who were certain about their answers. Most of the students who answered properly and were certain about their answers wrote down the equation of $\Delta p = p_2 - p_1$ as their reasons. On the other hand, students who were not certain with their answers mostly wrote $10 - (-20) = 30$ as their reasons. The students who answered A did not understand that a momentum change is the object momentum after collision reduced by the object momentum before collision so that students used the formula of $\Delta p = (-20) - 10 = -30$. However, there were not many students faced such problem (Table 1). Stu-

Figure 1. Questions to identify students' difficulties in determining momentum change in the forms of a) mathematic-quantitative, and b) diagram and symbol

Table 1. Students' Answer Distribution and Students' Levels of Conceptual Understanding about the question in Figure 1a

	Answer Distribution				Understanding Level Distribution			
Choices	Total number of Students		Students with the Indication of misconception		Understanding level	Code	N	%
	N	%	N	%				
A	9	5.14	5	2.86	High	SB	51	29.14
B	45	25.71	28	16.00	Misconception	M	43	24.57
C	24	13.71	10	5.71	Enough	C	34	19.43
D*	95	54.29	-	-	Low	L	45	25.71
NA	2	1.14	-	-	Unidentified	NA	2	1.14
Total	175	100	43	24.57	Total		175	100

* choices of correct answer

Table 2. Distribution of Students' Answers and Levels of Conceptual Understanding about the question in Figure 1b

	Answer distribution				Understanding Level Distribution			
Choice	Total number of Students		Students with the Indication of misconception		Understanding level	Code	N	%
	N	%	N	%				
A*	27	15.43	-	-	High	SB	8	4.57
B	6	3.43	3	1.71	Misconception	M	44	25.14
C	9	5.14	1	0.57	Enough	C	10	5.71
D	54	30.86	24	13.71	Low	L	105	60.00
E	71	40.57	16	9.14	Unidentified	NA	8	4.57
NA	8	4.57	-	-				
Total	175	100	44	25.14	Total		175	100

* choices of correct answer

dents who answered B did not understand that a vector equation is used to determine momentum change, so they only calculated the value of its momentum without paying attention to its direction so that students performed the calculation by using the formula of $\Delta p=10-20=-10$. This problem was the mostly faced difficulty by the students compared with the other problems (Table 1). It is relevant to the results of the research conducted by Graham & Berry (1996) who stated that students have problems in understanding the momentum concept as a vector. The students who answered C faced multi difficulties, namely the difficulties faced by students who answered A and B respectively. They did not understand that a vector addition is used in determining a momentum change and they were also wrong in formulating the momentum change. Those students performed the calculation by using the formula of $\Delta p=20-10=10$. Besides, the students who answered C also assumed that the momen-

tum change was similar with the last momentum experienced by the trolley.

Most of the difficulties faced by the students in solving the question in figure 1b were caused by their problems in depicting the vector reduction by using the polygon method. Most students chose the option E for this question (Table 2) for several reasons. First, the students moved the p_2 nucleus to p_1 tip (Figure 2a). Second, the students related the p_1 nucleus to the p_2 tip (Figure 2b). Third, the students moved p_1 nucleus to the p_2 tip, and then connected the p_1 tip to p_2 nucleus (Figure 2c). Students who answered B gave the correct answer by reversing the p_1 direction and moving the p_1 nucleus to the p_2 tip, but they made a mistake in determining the vector resultant by connecting the p_1 tip to the p_2 nucleus (Figure 2d). Figure 2a identified that the students could already describe a vector addition, but they found difficulties in describing a vector reduction. Besides, it might be because they did not understand
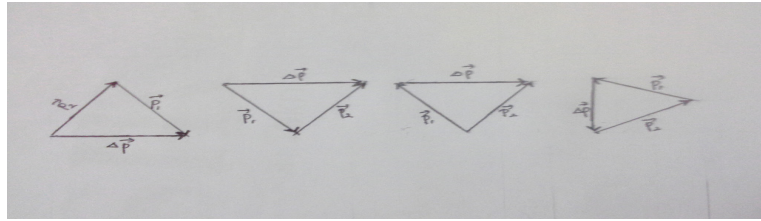
Figure 2. Examples of diagrams made by the students to solve the question in Picture 1b

Block A and B are pushed by the same constant force (**F**) until both of the blocks reach the finish line. Initially, the two blocks are still and block A mass is twice bigger than that of block B.

The momentum comparison of both blocks when reaching the finish line is . . . .

A. $\mathbf{p}_A = \frac{1}{2}\mathbf{p}_B$
B. $\mathbf{p}_A = \mathbf{p}_B$
C. $\mathbf{p}_A = 2\mathbf{p}_B$
D. $\mathbf{p}_A = \frac{1}{2}\sqrt{2}\mathbf{p}_B$
E. $\mathbf{p}_A = \sqrt{2}\mathbf{p}_B$

Figure 3. Question to Identify Students' difficulties related to Impulse-Momentum Theorem.

that a momentum change was a vector reduction. Figure 2b identified that the students had zero understanding about the determination of vector by using the polygon method. Figure 2c and 2d identified that the students already understood that a momentum change was a vector reduction so that they reversed the p_1 direction, but they did not use the polygon method correctly. The high number of students who answered this question incorrectly identified that students had problems of two-dimensional vector reduction and interpreting the value and direction of a vector in the form of graph. Such facts were relevant to Nguyen & Meltzer (2003) and Wutchana & Emarat (2011) research results. The question shown in figure 1b indicated that students also have difficulties when they were given problems related to other topics that they had studied before (Berek et al., 2016).

On the other side, there were also students who gave wrong answers because they assumed that a momentum change was similar with the last momentum experienced by an object. Those students answered D for the question in Figure 1b because the direction was the same as the final momentum direction. Such assumption was made by a relatively high number of students (Table 2). Some students who answered D for the question in Figure 1b also answered C for the

question in Figure 1a based on the same reason. The students' consistency showed that they have a common misconception. Such thought of students needed the most attention and needed to be changed in learning physics.

Students' difficulties Related to the Impulse-Momentum Theorem

In fact, based on the students' answers to the questions that include a mass of an object, initial and terminal velocities of an object, and the time interval of the collision, it was found that they had understood the relation between impulse and momentum in the form of I=Δp equation. In relation with those questions, the students, having the plug and chug tendency, could answer correctly when they were asked about the average forces acting on an object. It was possible because the variables needed to answer the questions were already given in the questions to be substituted into the equation of I=Δp. Therefore, when they had those variables, they could directly choose the correct equation (Walsh et al., 2007; Ding, 2011).

However, they could not activate their memory about the relation between impulse and momentum when they were given the question shown Figure 3. It revealed that students who know a mathematic equation are not guaranteed

to be able to apply such equation in physics (Sutopo, 2016). As a consequence, many students were wrong in answering questions of which contexts do not directly provide all variables to be substituted into the equation. In this research, no one could answer correctly to such kind of question. The distribution of the students' answers and students' conceptual understanding levels about the question shown in Figure 3 are completely presented in Table 3.

Most students answered options A and C when they did the question shown in Figure 3 (Table 3). On the other hand, the students who answered option C had a tendency to think that an object with a bigger mass has a bigger momentum. The question in Figure 3 informs that block A mass is twice larger than that of block B, so the students assumed that block A momentum was also twice as significant than that of block B. In contrast, students who answered A thought that the faster an object moves, the bigger the momentum of such object would be. Since the question in Figure 3 informing that a similar force act on both block A and B with block A mass that is twice bigger than that of block B, students could conclude that the velocity of block A was half of the block B velocity, so block A had a half momentum of the block B momentum. Students who answered A and C were not likely to be a lack of understanding that a momentum is a result of timing the mass and velocity of an object, so both of the mass and velocity values of an object influence its momentum. However, the students failed to activate such understanding since they had another dominant thought while solving the question in such context (Itza-Ortiz et al., 2004; Hrepic et al., 2010; Khasanah et al., 2016). Such issue needed to be paid attention and changed in physics learning.

To such kind of question, 2 students answered D (Table 3) could complete the questions in more appropriate steps. They searched for the velocity comparison by using the equation of $v_A:v_B=\sqrt{(2a_A s)}:\sqrt{(2a_B s)}=\sqrt{(a_A)}:\sqrt{(a_B)}=\sqrt{(F/m_A)}:\sqrt{(F/m_B)}$ then they compared $p_A:p_B=m_A v_A:m_B v_B$. Unfortunately, they determined the comparison of block A momentum in the way they should determine the comparison of block B momentum, and vice versa.

Students Difficulties Related to the Momentum Conservation Law

The application of $m_1v_1+m_2v_2=m_1v'_1+m_2v'_2$ equation of momentum conservation law by the students in solving a problem related to collision (a discovery from question that is not discussed in this article) does not guarantee that they know that they should use the law since zero force resultant acts when the collision happens. They did not understand that a force acting in this system was the action and reaction that had the same values but opposite directions. The finding was obtained based on the students' answers for the question presented in Figure 4. Only 2.29 % students could answer correctly to this question. The distributions of the students' answers and conceptual understanding levels of the question shown in Figure 4 are completely presented in Table 4.

Most students answered B and D while doing the question in Figure 4 (Table 4). Students who answered B assumed that force is a pushing or pulling movement, so only an object which is pushing or pulling has force. When the question informed that student A pushes student B, the students concluded that it is only student A who gives force. Students who answered D had some thoughts, including an object with bigger

Table 3. Students' Answer Distribution and Conceptual Understanding Level about the Question in Figure 3

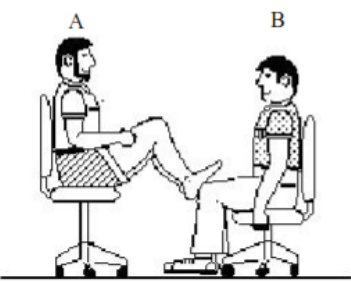| Choices	Answer Distribution				Understanding Level Distribution			
	Total Number of Students		Students with the Indication of misconception		Understanding Level	Code	N	%
	N	%	N	%				
A	69	39.43	26	14.86	High	SB	0	0.00
B	7	4.00	3	1.71	Misconception	M	85	48.57
C	96	54.86	54	30.86	Enough	C	0	0.00
D	2	1.14	2	1.14	Low	L	89	50.86
E*	0	0.00	-	-	Unidentified	NA	1	0.57
NA	1	0.57	-	-				
Total	175	100	85	48.57	Total		175	100

* choices of correct answer

Look at the picture!
Student A has 65 kg mass, and student B has 50 kg mass. They are sitting facing each other on two identical chairs. Student A then pushes student B with his feet as shown in the picture, which causes the chairs they are sitting to move.
Which statement is correct about the force acting during the interaction between student A and B?
A.   Both students do not give any force to each other
B.   Student A gives force to student B. However, student B does not give any force at all
C.   Every student gives force with each other, but the force from student B is bigger than the force from student A
D.   Every student gives force to each other, but the force from student A is bigger than the force from student B
E.   Every student gives the same force to each other.

Figure 4. Question to reveal Students' Difficulties in Understanding Momentum Conservation Law.

Table 4. Distributions of students' answers and conceptual understanding levels about the question in Figure 4

	Answer Distribution				Understanding Level Distribution			
Choice	Total Number of Students		Students with the Indication of misconception		Understanding Level	Code	N	%
	N	%	N	%				
A	0	0.00	0	0.00	High	SB	3	1.71
B	54	30.86	17	9.71	Misconception	M	51	29.14
C	9	5.14	5	2.86	Enough	C	0	0.00
D	99	56.57	29	16.57	Low	L	112	64,00
E*	4	2.29	-	-	Unidentified	NA	9	5.14
NA	9	5.14	-	-				
Total	175	100	51	29.14	Total		175	100

* choices of correct answer

mass, gives a bigger force, so they assumed that force done by student A weighing 65 kg was larger than that done by student B weighing 50 kg. Also, an object which pushes/pulls gives a bigger force than an object which receives the force, so the force done by student A is larger because student A is the one pushing student B. In solving such question, the students faced difficulties in understanding that if two objects interact with each other, each object will give the same force but with opposite directions (Brown, 1989; Sayre et al., 2012). However, it did not mean that they did not understand about the action-reaction force of $F_{action} = -F_{reaction}$. Similar with the way the students answered the question in Figure 3, they used more dominant knowledge in their thought while answering the question in Figure 4 (Itza-Ortiz, et al., 2004; Hrepic et al., 2010; Khasanah et al., 2016).

The problems above would result in other mistakes done by the students, such as their difficulties in understanding that in a collision, the total momentum value is the conserved one, not the momentum value of each object colliding with each other. It can be seen from the students' answers for a question related to "a white marble collides with a red marble that is motionless, and after the collision, the white marble and the red marble move in the same direction but at different speeds." When they were asked to determine the correct statement, most of them chose the statement that only the white marble which was conserved, and not both the white and red marbles. It was relevant to the results of research done by Singh & Rosengrant (2003) who found a students' assumption that momentum conservation was the momentum of each object colliding with each other. Thus, students needed to understand well the situation in which the momentum conservation can be applied by reviewing the resultant acting in one object rather than the resultant force serving in the whole system. It could help students to understand that by reviewing the system, the force resultant becomes zero. In other words, the impulse acting on the system is zero, so the momentum change is equal to zero. It means there are not any changes in the momentum value before and after the collision.

CONCLUSION

Most students get difficulties in solving impulse and momentum problems. It was because they failed to activate their appropriate concepts relevant to the problem. Students' difficulties were not only caused by their deficient conceptual understanding about impulse and momentum, but also their weak understanding about the relationship among force, acceleration, and velocity. Another difficulty was due to their deficient skill to work with vector. Representation format of the problem also contributed to students' difficulty. Students' performance in solving problem that is presented in mathematic-quantitative representation is better than that presented in diagram or figure representation.

REFERENCES

Alwan, A. A. (2011). Misconception of heat and temperature Among physics students. *Procedia-Social and Behavioral Sciences*, *12*, 600-614.

Berek, F. X., Sutopo, S., & Munzil, M. (2016). Enhancement of junior high school students'concept comprehension in hydrostatic pressure and archimedes law concepts by predict-observe-explain strategy. *Jurnal Pendidikan IPA Indonesia*, *5*(2): 230 -238.

Besson, U. (2004). Students' conceptions of fluids. *International Journal of Science Education*, *26*(14), 1683-1714.

Brown, D. E. (1988). Students' Concept of Force: The Importance of Understanding Newton's Third Law. Physics Education, 24 (6): 353-358.

Bryce, T. G. K., & MacMillan, K. (2009). Momentum and kinetic energy: Confusable concepts in secondary school physics. *Journal of Research in Science Teaching*, *46*(7), 739-761.

Chambers, S. K., & Andre, T. (1997). Gender, prior knowledge, interest, and experience in electricity and conceptual change text manipulations in learning about direct current. *Journal of Research in science Teaching*, *34*(2), 107-123.

Close, H. G., & Heron, P. R. (2010). Research as a guide for improving student learning: An example from momentum conservation. *American Journal of Physics*, *78*(9), 961-969.

Dalaklioğlu, S., & Sekercioğlu, A. P. D. A. (2015). Eleventh grade students'difficulties and misconceptions about energy and momentum concepts. *International Journal of New Trends in Education and Their Implications*, *6*, 13-21.

Demirci, N. (2008). Misconception patterns from students to teachers: an example for force and motion concepts/Ejemplos de ideas alternativas transmitidas de los estudiantes a los profesores: temas: fuerza y movimiento. *Journal of Science Education*, *9*(1), 55-59.

Ding, L., Reay, N., Lee, A., & Bao, L. (2011). Exploring the role of conceptual scaffolding in solving synthesis problems. *Physical Review Special Topics-Physics Education Research*, *7*(2), 020109.

Docktor, J. L., & Mestre, J. P. (2014). Synthesis of discipline-based education research in physics. *Physical Review Special Topics-Physics Education Research*, *10*(2), 0201191-02011958.

Elmehdi, H., Pistorius, S., & Suleiman, B. M. 2013. Difficulties Faced by College Students in Introductory Physics. *A Case Study. Physics Education, 29(1),* 7.

Graham, T., & Berry, J. (1996). A hierarchical model of the development of student understanding of momentum. *International Journal of Science Education*, *18*(1), 75-89.

Gönen, S., & Kocakaya, S. (2010). A cross-age study on the understanding of heat and temperature. *Eurasian Journal of Physics and Chemistry Education (EJPCE)*, *1*(2), 1-15.

Halim, L., Yong, T. K., & Meerah, T. S. M. (2014). Overcoming students' misconceptions on forces in equilibrium: An action research study. *Creative Education*, *5*(1), 1032-1042.

Halloun, I. A., & Hestenes, D. (1985). The initial knowledge state of college physics students. *American journal of Physics*, *53*(11), 1043-1055.

Hammer, D. (1996). More than misconceptions: Multiple perspectives on student knowledge and reasoning, and an appropriate role for education research. *American Journal of Physics*, *64*(10), 1316-1325.

Hasan, S., Bagayoko, D., & Kelley, E. L. (1999). Misconceptions and the certainty of response index (CRI). *Physics education*, *34*(5), 294-299.

Hestenes, D. (1987). Toward a modeling theory of physics instruction. *American journal of physics*, *55*(5), 440-454.

Hestenes, D., & Wells, M. (1992). A mechanics baseline test. *The physics teacher*, *30*(3), 159-166.

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. *The physics teacher*, *30*(3), 141-158.

Hrepic, Z., Zollman, D. A., & Rebello, N. S. (2010). Identifying students' mental models of sound propagation: The role of conceptual blending in understanding conceptual change. *Physical review special topics-physics education research*, *6*(2), 0201141-02011418.

Hung, W., & Jonassen, D. H. (2006). Conceptual understanding of causal reasoning in physics. *International Journal of Science Education*, *28*(13), 1601-1621.

Itza-Ortiz, S. F., Rebello, S., & Zollman, D. (2003). Students' models of Newton's second law in mechanics and electromagnetism. *European Journal of Physics*, *25*(1), 81-82.

Ivowi, U. M. O. (1986). Students' misconceptions about conservation principles and fields. *Research in Science & Technological Education*, *4*(2), 127-137.

Kautz, C. H., Heron, P. R., Shaffer, P. S., & McDer-

mott, L. C. (2005). Student understanding of the ideal gas law, Part II: A microscopic perspective. *American Journal of Physics*, *73*(11), 1064-1071.

Khasanah, N., Wartono, W., & Yuliati, L. (2016). Analysis of mental model of students using isomorphic problems in dynamics of rotational motion topic. *Jurnal Pendidikan IPA Indonesia*, *5*(2), 186-191.

Kryjevskaia, M., Stetzer, M. R., & Heron, P. R. (2011). Student understanding of wave behavior at a boundary: The limiting case of reflection at fixed and free ends. *American Journal of Physics*, *79*(5), 508-516.

Kryjevskaia, M., Stetzer, M. R., & Heron, P. R. (2012). Student understanding of wave behavior at a boundary: The relationships among wavelength, propagation speed, and frequency. *American Journal of Physics*, *80*(4), 339-347.

Lawson, A. E. 1995. *Science teaching and the development of thinking.* Belmont, CA: Watsworth Publishing Company.

Lawson, R. A., & McDermott, L. C. (1987). Student understanding of the work-energy and impulse-momentum theorems. *American Journal of Physics*, *55*(9), 811-817.

López, M. L. (2003). Angular and linear acceleration in a rigid rolling body: students' misconceptions. *European journal of physics*, *24*(6), 553-563.

Loverude, M. E., Heron, P. R. L., & Kautz, C. H. (2010). Identifying and addressing student difficulties with hydrostatic pressure. *American Journal of Physics*, *78*(1), 75-85.

McDermott, L. C., Rosenquist, M. L., & Van Zee, E. H. (1987). Student difficulties in connecting graphs and physics: Examples from kinematics. *American Journal of Physics*, *55*(6), 503-513.

Nguyen, N. L., & Meltzer, D. E. (2003). Initial understanding of vector concepts among students in introductory physics courses. *American journal of physics*, *71*(6), 630-638.

Oliveira, V. (2011). Angular and linear accelerations of a rolling cylinder acted by an external force. *European Journal of Physics*, *32*(2), 381-388.

Ortiz, L. G., Heron, P. R., & Shaffer, P. S. (2005). Student understanding of static equilibrium: Predicting and accounting for balancing. *American Journal of Physics*, *73*(6), 545-553.

Osborne, R. J., Bell, B. F., & Gilbert, J. K. (1983). Science teaching and children's views of the world. *European Journal of Science Education*, *5*(1), 1-14.

Potgieter, M., Malatje, E., Gaigher, E., & Venter, E. (2010). Confidence versus performance as an indicator of the presence of alternative conceptions and inadequate problem-solving skills in mechanics. *International Journal of Science Education*, *32*(11), 1407-1429.

Pride, T. O. B., Vokos, S., & McDermott, L. C. (1998). The challenge of matching learning assessments to teaching goals: An example from the work-energy and impulse-momentum theorems. *American Journal of Physics*, *66*(2), 147-

157.

Rosenblatt, R., & Heckler, A. F. (2011). Systematic study of student understanding of the relationships between the directions of force, velocity, and acceleration in one dimension. *Physical Review Special Topics-Physics Education Research*, *7*(2), 0201121-02011220.

Sayre, E. C., Franklin, S. V., Dymek, S., Clark, J., & Sun, Y. (2012). Learning, retention, and forgetting of Newton's third law throughout university physics. *Physical Review Special Topics-Physics Education Research*, *8*(1), 0101161-01011610.

Sencar, S., & Eryilmaz, A. (2004). Factors mediating the effect of gender on ninth-grade Turkish students' misconceptions concerning electric circuits. *Journal of Research in Science Teaching*, *41*(6), 603-616.

Serway, R. A., & Jewett, J. W. 2014. *Physics for Scientists and Engineers with Modern Physics: Ninth Edition.* USA: Cengage Learning.

Singh, C., & Rosengrant, D. (2003). Multiple-choice test of energy and momentum concepts. *American Journal of Physics*, *71*(6), 607-617.

Stetzer, M. R., Van Kampen, P., Shaffer, P. S., & McDermott, L. C. (2013). New insights into student understanding of complete circuits and the conservation of current. *American Journal of Physics*, *81*(2), 134-143.

Stylos, G., Evangelaki, G. A., & Kotsis, K. T. (2010). Misconceptions on classical mechanics by freshman university students: A case study in a Physics Department in Greece. *Themes in Science and Technology Education*, *1*(2), 157-177.

Sutopo, S. (2016). Students'understanding of fundamental concepts of mechanical wave. *Jurnal Pendidikan Fisika Indonesia*, *12*(1), 41-53.

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), 338-352.

Torigoe, E. (2008). *What kind of math matters? A study of the relationship between mathematical ability and success in physics.* University of Illinois at Urbana-Champaign.

Trowbridge, D. E., & McDermott, L. C. (1980). Investigation of student understanding of the concept of velocity in one dimension. *American journal of Physics*, *48*(12), 1020-1028.

Trowbridge, D. E., & McDermott, L. C. (1981). Investigation of student understanding of the concept of acceleration in one dimension. *American Journal of Physics, 49* (3), 242-253.

Turányi, T., & Tóth, Z. (2013). Hungarian university students' misunderstandings in thermodynamics and chemical kinetics. *Chemistry Education Research and Practice*, *14*(1), 105-116.

Vreeland, P. (2002). Analyzing simple circuits. *The Physics Teacher*, *40*(2), 99-100.

Walsh, L. N., Howard, R. G., & Bowe, B. (2007). Phenomenographic study of students' problem

solving approaches in physics. *Physical Review Special Topics-Physics Education Research*, *3*(2), 0201081-02010812.

Widarti, H. R., Permanasari, A., & Mulyani, S. (2016). Student misconception on redox titration (a challenge on the course implementation through cognitive dissonance based on the multiple representations). *Jurnal Pendidikan IPA Indonesia*, *5*(1), 56-62.

Wijaya, C. P., & Muhardjito, M. (2016). The diagnosis of senior high school class x mia b students

misconceptions about hydrostatic pressure concept using three-tier. *Jurnal Pendidikan IPA Indonesia*, *5*(1), 13-21.

Wutchana, U., & Emarat, N. (2011). Students' understanding of graphical vector addition in one and two dimensions. *Eurasian Journal of Physics and Chemistry Education*, *3*(2), 102-111.

Yalcin, M., Altun, S., Turgut, U., & Aggül, F. (2009). First year Turkish science undergraduates' understandings and misconceptions of light. *Science & Education*, *18*(8), 1083-1093.