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Conceptual Understanding and Representation Quality on Newton's Laws through Multi-Representation Learning

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Abstract: Students who have a good comprehension on learned concepts will be able to present the concepts by using multi-representation. This study seeks to investigate the improvement of junior high students' understanding of the concept of Newton's Laws and the quality of representations used in solving problems pertaining to Newton's Law of Motions. The results showed that the students' understanding of the learned concepts increased from the average of 35.32 to 78.97 with an effect size of 2.66 (strong) and N-gain of 0.68 (average). The quality of each type of students' representations also increased from level 1 and level 2 to level 3.

Key Words: Newton's Laws, representation quality, concept comprehension, multi representation learning

Abstrak: Siswa yang memiliki penguasaan konsep yang baik akan mampu merepresentasikan konsep dengan menggunakan multi representasi. Penelitian ini bertujuan untuk mengetahui peningkatan pemahaman konsep siswa SMP pada materi Hukum Newton dan kualitas representasi yang digunakan dalam menyelesaikan masalah pada materi Hukum Newton. Hasil penelitian menunjukkan bahwa penguasaan konsep siswa meningkat dari rata-rata 35,32 menjadi 78,97 dengan effect size sebesar 2,66 (kuat) dan N-gain sebesar 0,68 (sedang). Kualitas tiap jenis representasi siswa juga mengalami peningkatan dari level 1 dan level 2 naik menjadi level 3.

Kata kunci: hukum Newton, kualitas representasi, pemahaman konsep, pembelajaran multi representasi

Science learning places great emphasis on the provision of direct learning experiences through scientific inquiry. This is so, for students will acquire new knowledge based on the process of exploring and understanding their natural surroundings scientifically. To meaningfully comprehend the new knowledge, the students have to independently employ their mental faculty to process all information they receive so that it can be synergistically linked to their prior knowledge (Sutopo, 2014). The linkage between the structures of new and prior will make learning more meaningful (Zubaidah, et al., 2013a; Zubaidah et al., 2013b).

One way to know the students' knowledge of certain natural phenomena is to ask them to describe such phenomena by using various representations such as verbal performace, sketches, drawings, diagrams, mathematical formulas, gestures and the like. (Heuvelen 1991; Heuvelen & Zhou, 2001; Prain & Waldrip, 2007; Kohl et al., 2007; Ainsworth, 2009; Rosengrant et al., 2009; Sutopo et al., 2011; Yusuf, 2012; Sari et al., 2015). Thus, the students are said to have mastered particular scientific concepts if they are able to represent the concept with different representational formats, known as multi representations (Abdurrahman, et al, 2011; Von Korff & Rebello, 2012). Multi representation is believed to alleviate difficulties the students face in studying the scientific concepts.

Multi-representation is considered as the key to learning science (Kohl et al, 2007) because it can represent the concept of science into various forms, namely, verbal or physical forms, drawings, and mathematical formulas. The use of multiple-representation

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helps students explain the physical phenomenon and solve scientific problems (Bartimoro et al, 2010). To firmly plant the scientific concepts in the students' mind, the appearance of various representations is believed to better assist students in understanding the concepts learned (Suhandi & Wibowo, 2012). A multi-representation approach therefore wields potential to yield an effective learning process.

In science learning, Newton's Law is a basic concept the students have to understand because it will help them successfully comprehend other learning materials. It follows that a more complicated concept will be understood if a more basic concept has been previously mastered. Learning Newton's Law requires an understanding of the concepts which means that the students are supposed to be able to employ Newton's Law principles to explain and predict natural phenomena; they, moreover, are supposed to know how to apply this understanding efficiently in the conduct of scientific observations and in practical reasoning (NAEP, 2005).

However, learning Newton's Law poses considerable problems in view of the fact that most students find it difficult to understand Newton's Law I, II, and III. The problem, furthermore, lies in the fact that the students tend to only memorize them, but they actually do not possess thorough understanding about their essence (Malichatin, 2013). Moreover, there remains a frequently held misconception among the students about the concept of Newton's Law 1 particularly as they tend to think that moving objects always have a force, including those moving at constant speed (Amin et al, 2015).

With regard to Newton's Law II, the students face difficulty in understanding the components of total force (Singh & Schunn, 2009), making correct free-body diagrams to solve problems residing in Newton's Law II (Heckler, 2010), and determining the magnitude and direction of the acceleration of moving objects (Sutopo et al, 2012); they also tend to assume that the acceleration and velocity are the same (Amin et al, 2015). Pertaining to Newton's Law III, the difficulties comprise determining pairs of reaction-action forces in situations involving gravitational interactions although they can make good reasoning that the action and reaction forces are the same by applying the principles of Newton's Law III (Zhou et al, 2015).

Multi-representation is of great importance to be applied in learning. Through multi-representation, the students can build concepts and overcome problems arising as they study science. Therefore, multi-representation learning can be used as an optional learning strategy.

METHOD

This study employed mixed-method approach with an embedded experimental model (Creswell & Clark, 2007), for it was attempt to deeply explore research subjects. The subjects of this study comprised 25 eighth grade students of SMP IT Asy-syadzili, a junior high school located in Sumber Pakis, Malang. A test encompassing 14 multiple choice items and questions about the Newton's Law was used as the instrument in this study. The test was administered to measure the students' comprehension about the concept and to know how they reason out their answers. The reasons given by students can be expressed in various forms of representation: verbal (text), diagrams and mathematical formulas. The results of the multiple-choice items were quantitatively analyzed while the students' arguments were treated as qualitative data. Forms of representations used by the students in answering the questions were determined by using coding rubric. The coding rubric is shown in Table 1.

The data were analysed both quantitatively and qualitatively. The quantitative analysis was based on pre-test and post-test score while the qualitative analysis was based on the students' reasons and steps pertaining to how they solved the problems given to investigate whether their reasoning changed. The learning sequences designed for each topic are described in Figure 1.

Table 1. Rubric and Types of Students' Representations

Representations	Definition
Verbal	The students' answers are in the form of texts comprising sentences used to express physical ideas or concepts completely
Mathematical	There are mathematical formula or symbols represented in the students' answers pertaining to physical concepts and steps to solve the problems
Force-Diagram	There is an analysis of force-diagram employed by the students in their answers

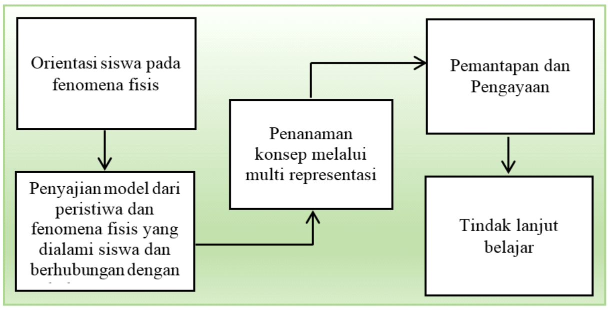


Figure 1. Multi-representation Learning Sequences

RESULTS

Comprehension of The Concept

The results of the statistical descriptions of the pre-test, post-test and N-Gain can be seen in Table 2.

Table 2. Statistical Description of Pre-test, Post-test and N-Gain

	Pre	*Post*	*N-Gain*
Total of Data	25	25	25
Average	5,16	11,16	0,68
Standard Deviation	1,748	2,672	0,316
Skewness	0,141	-0,513	-0,686
The Lowest Score	2	6	0
The Highest Score	9	14	1

Note: Range 0-14

The skewness for data gained from pre-test and post-test rested in interval [-1, 1]. Referring to Morgan *etc* (2004), paired sample t-test can be utilized to see the mean difference between the pre-test and the post-test in the same units of samples. This is so, for it is able to identify how the average changes after the multi-representation learning is applied to understand Newton's Laws. The results of the calculation showed t (*df=24*) = –10.3407 with *p=0.000* (two sides). Moreover, the results of the analysis showed that statistically there was a significant difference between the pre-test and post-test. The total average for the pre-test reached 11.16, which is bigger than the pre-test reaching 5.16 in average. Therefore, it can be deduced that the multi-representation learning applied in this research effectively improves the students' understanding of Newton's Laws.

The average score of N-gain for each student reached 0.68. This score comes between 0.3 and 0.7, which is categorized as average (Hake, 1998) or middle high (Sutopo & Waldrip, 2014). The score for Cohen's *d-effect size* reached 2.66. This is categorized as strong or very high (Morgan et al., 2004; Ellis, 2010). Hence, it can be concluded that the multi-representation learning applied in this research strongly gives a positive impact pertinent to the improvement of the students' understanding.

Such an improvement can be construed by looking at the shift of the students' correct answers in the pre-test and post-test, as shown in Figure 2.

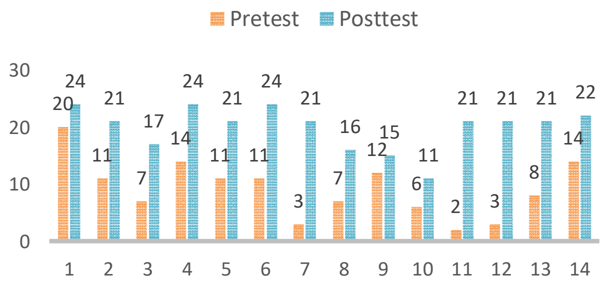


Figure 2. Distribution of Correct Answers for Newton's Laws Material

For Newton's Law I, the lowest shift was on item No. 1. It only escalated by 12%. However, in the post-test, 96% of the students solved the item correctly, while in the pre-test there were 76% of them did so. Moreover, there was a big shift for item No. 3 by 40%. However, in the post-test, only 68% of the students (< 75%) had the correct answer. The *N-Gain* for this item is categorized as average.

For Newton's Law II, there was a low shift for items No. 8, 9 and 10. The lowest shift was on item No 9, escalating by 14%. For this item, the number of the students who had the correct answer in the post-test reached only 60%. Such a small shift also occurred in item No. 10, reaching only 20%. For this item, only 40% of the students had the correct answer in the post-test. There were still many students who could not provide the correct answer in the post-test. The *N-Gain* for items No 9 and 10 is categorized as low. A small shift also occurred in item No. 8, reaching 36% categorized as average for *N-Gain* score.

For Newton's Law III, there was a small shift particularly in item No. 14. It reached 32%, but 88% of the students had the correct answer in the post-test for this item.

The Representation Quality

The data for the quality of the students' representations were gained from written reasons given by the students and ways of solving problems employed by the students to answer the multiple-choice items in which they were also asked to provide reasons for the choice. In this research, types of representations that the students can use are verbal, mathematical and free-diagram. These representations were further analysed by using the representation quality rubric. The average score for each type of representations in the pre-test and post-test improved, particularly for verbal and mathematical representation. In the pre-test, the quality of the verbal representation reached Level 1 (inadequate) and improved to Level 3 (adequate) in the post-test. Moreover, in the pre-test, the quality of the mathematical representation was on Level 0 (missing) and improved to level 3 (adequate) in the post-test. For the free-diagram representation, there was no change found as it did not appear both in the pre-test and post-test.

The change in the students' representation quality for Newton's Law 1 can be seen in the students' explanations given for items No. 1, 2, 3, and 4. For these four items, all of which are about Newton's Law 1, the students were asked to construct verbal representation. For this kind of representation, there are four categories provided. The students whose verbal representation categorized as Level 3 (adequate) mean that they are able to make a clear and logical verbal representation, supported by relevant and correct explanations of physical concepts. Those placed in Level 2 (need some improvement) mean that the explanation of the concept is incomplete though the reasons given are clear and logical. For Level 1 (inadequate), it means that the verbal representation given by the students are lack of clarity and devoid of physical concepts or they apply wrong concepts. The last is Level 0 (missing) which means that there is no verbal representation demonstrated by the students.

Item No. 1

Figure 3 summarizes the distribution and frequency of the students' verbal representation quality for item No. 1 in the pre-test and post-test.

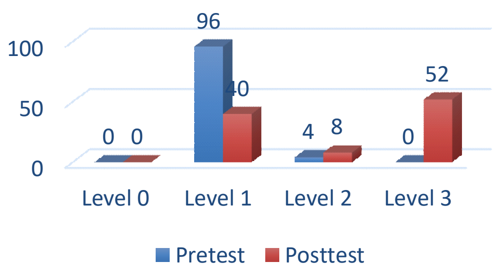
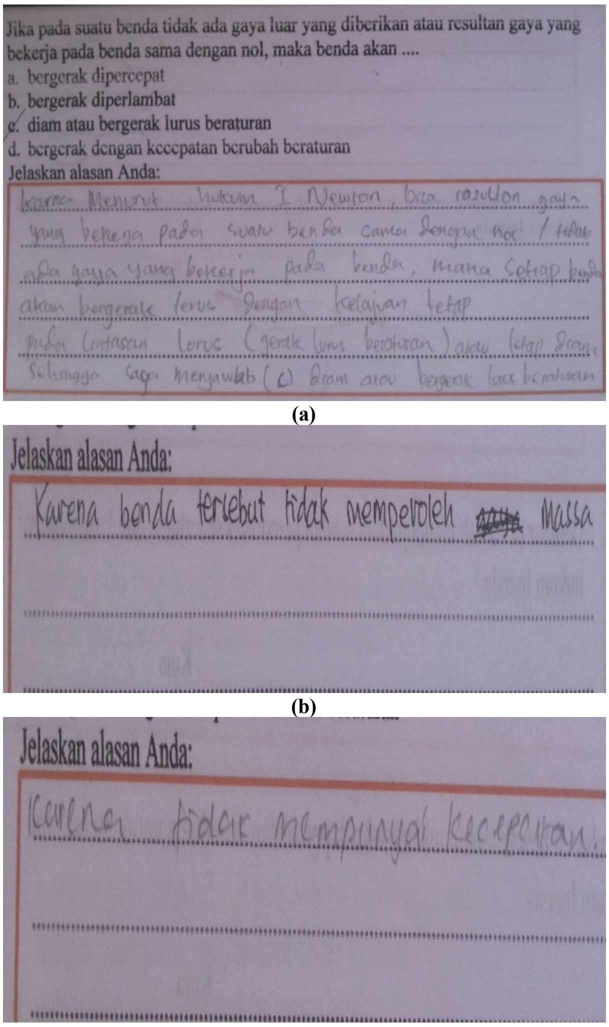


Figure 3. Distribution and Frequency of Verbal Representation Quality in Item No. 1

Instances of verbal representations built by the students are shown in Figure 4. Figure (4a) showed that the verbal representation was already fitting. On the other hand, Figures (4b) and (4c) showed that the representation was not correct.



(a) (b) (c)

Figures 4. Instances of Students' Verbal Representation in Item No. 1

Item No. 2

Figure 5 summarizes the distribution and frequency of the students' mathematical representation quality for item No. 2 in pre-test and post-test.

Some instances of mathematical representation built by the students are shown in Figure 6. Figure (6a) showed that there was no mathematical representation demonstrated by the students. Figure (6b) showed that the representation was incorrect. Moreover, Figure (6c) showed that the representation was correct. The difficulties faced by the students in representing the mathematical formula lied in their lack of

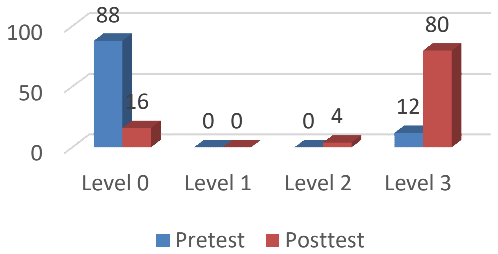
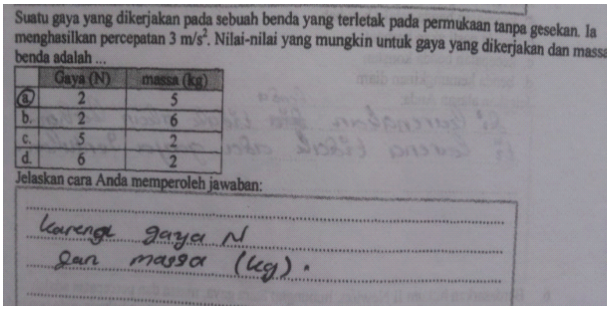


Figure 5. Distribution and Frequency of Mathematical Representation Quality in Item No. 2

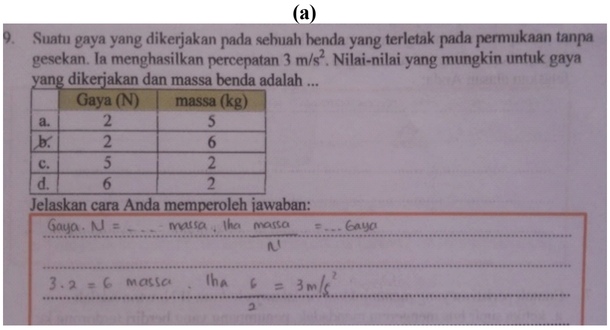

Suatu gaya yang dikerjakan pada sebuah benda yang terletak pada permukaan tanpa gesekan. Ia menghasilkan percepatan 3 m/s². Nilai-nilai yang mungkin untuk gaya yang dikerjakan dan massa benda adalah ...

	Gaya (N)	massa (kg)
a.	2	5
b.	2	6
c.	5	2
d.	6	2

Jelaskan cara Anda memperoleh jawaban:

karena gaya N dan massa (kg).

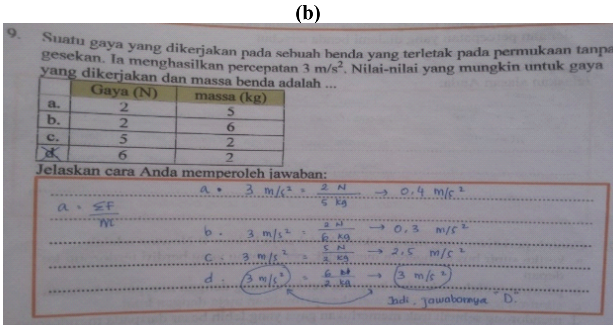
(a)


9. Suatu gaya yang dikerjakan pada sebuah benda yang terletak pada permukaan tanpa gesekan. Ia menghasilkan percepatan 3 m/s². Nilai-nilai yang mungkin untuk gaya yang dikerjakan dan massa benda adalah ...

	Gaya (N)	massa (kg)
a.	2	5
b.	2	6
c.	5	2
d.	6	2

Jelaskan cara Anda memperoleh jawaban:

(b)


9. Suatu gaya yang dikerjakan pada sebuah benda yang terletak pada permukaan tanpa gesekan. Ia menghasilkan percepatan 3 m/s². Nilai-nilai yang mungkin untuk gaya yang dikerjakan dan massa benda adalah ...

	Gaya (N)	massa (kg)
a.	2	5
b.	2	6
c.	5	2
d.	6	2

Jelaskan cara Anda memperoleh jawaban:

(c)

Figure 6. Instances of Students' Mathematical Representation in Item No. 2

understanding of Newton's Law II pertinent to the inseparable connection of mass, force, and velocity. The students were not able to verbally reason out the linkage correctly so that they were not able to make the representation of the mathematical formula. It plausibly was caused by the fact that the students only memorize the formula, but they do not thoroughly comprehend what it actually means. Moreover, there was a student who was able to make the representation of the mathematical formula correctly, but the student did not solve the item correctly due to miscalculation.

Item No. 3

For Item No. 3, the students were asked to construct verbal representation. In the pre-test, the quality of the representation was located in level 0 (missing) indicating that there was no verbal representation demonstrated by the students. In the post-test, there was a change in the quality, moving to level 3 (adequate). Figure 7 summarizes the distribution and frequency of the students' verbal representation level for item No. 1 in the pre-test and post-test.

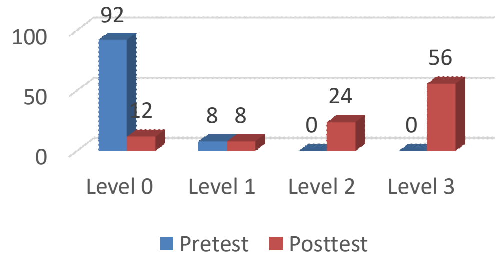
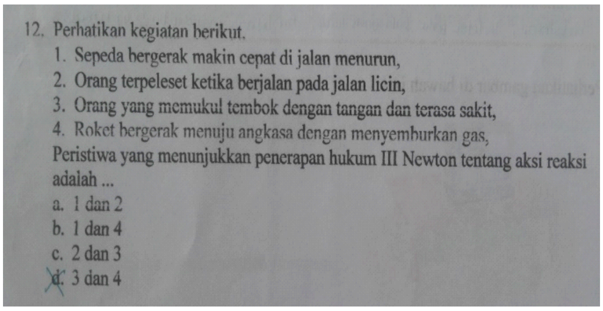


Figure 7. Distribution and Frequency of Verbal Representation Quality in item No. 3

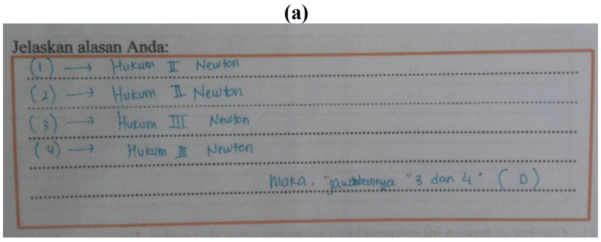

12. Perhatikan kegiatan berikut.

1. Sepeda bergerak makin cepat di jalan menurun,
2. Orang terpeleset ketika berjalan pada jalan licin,
3. Orang yang memukul tembok dengan tangan dan terasa sakit,
4. Roket bergerak menuju angkasa dengan menyemburkan gas,

Peristiwa yang menunjukkan penerapan hukum III Newton tentang aksi reaksi adalah ...

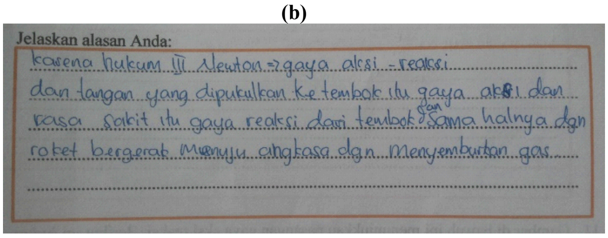
a. 1 dan 2
b. 1 dan 4
c. 2 dan 3
d. 3 dan 4

(a)


Jelaskan alasan Anda:

(1) → Hukum II Newton
(2) → Hukum I Newton
(3) → Hukum III Newton
(4) → Hukum III Newton
Maka, jawabannya "3 dan 4" (D)

(b)


Jelaskan alasan Anda:

karena hukum III Newton = gaya aksi - reaksi dan tangan yang dipukulkan ke tembok itu gaya aksi dan rasa sakit itu gaya reaksi dari tembok dan sama halnya dgn roket bergerak menuju angkasa dgn menyemburkan gas

(c)

Figure 8. Instances of Students' Verbal Representation in Item No. 3

Figure 8 shows the students' verbal representation. Figure (8a) is item No. 8. Figures (8b) and (8c) showed that the verbal representation was correct already.

DISCUSSION

For Newton's Law I, there were some points in which the students still demonstrated lack of understanding of the concept and this was hard to change even after the multi-representation learning was done. Those misconceptions are summarized as follows. First, an object whose net force is zero is only unmoving objects possessing zero velocity and mass whose motion has been interrupted. This misconception occur-red because the students did not really understand what the net force equal to zero means ($\Sigma\overline{F}=0$), as proposed in Newton's Law I. The students thought that $\Sigma\overline{F}=0$ means the object is devoid of force. Moreover, they also perceived that $\Sigma\overline{F}=0$ has zero velocity (v=0). Actually, when $\Sigma\overline{F}=0$ occurs, there is a force exerting upon the object equal to zero and the moving object has a constant speed, which is cer-tainly not zero. The students tend to not fully under-stand the meaning of Newton's Laws, but they, on the other hand, tend to merely memorize how the laws are articulated (Malichatin, 2013). Secondly, it is diffi-cult for the students to differentiate velocity from ac-celeration. They tend to think that both of them are the (Amin etc, 2015). Thirdly, the students thought that it is the mass that causes an object persist its state of motion, not due to the effect of the net force exerted to the object. This occurred as the students did not carefully analyse the force acting on an object. This finding corresponds with the results of the study conducted by Sari etc (2015) stating that it is still hard for the students to analyse the net force.

For Newton's Law II, through verbal representation learning, the students were able to understand the relationship between force, mass and acceleration. Furthermore, they were able to present its mathematical formula and operate correct calculations. There was a change in the types of representation constructed by the students in which they were not only able to present a concept verbally, but they were also able to transform such a verbal representation into its math-ematical representation. Such a practice is beneficial for the students as the use of some representations help them understand a concept and solve a problem (Rosengrant et al., 2009). Moreover, interacting with various representations as diagrams, graphs, and math-ematical representations can be of great help when it deals with learning scientific concepts which are really complex (Ainsworth, 2009).

This research also successfully identified difficulties faced by the students in understanding Newton's Law II. First, the students were still not able to correctly make a connection between mass, force, and acceleration so that it affected the mathematical representation they made. The students thought that force acting on an object will interrupt its state of motion. Therefore, they concluded that in Newton's Law III the net force reacts oppositely to an object's acceleration and there were some students even thinking that force is opposite an object's mass. Actually, acceleration ($\vec{a}$) and force ($\vec{F}$) are equal, but they are inversely proportional to mass (*m*). Moreover, the students also opined that force affects an object's mass. They found it difficult to understand how force and mass affect an object's acceleration and to make its mathematical representation. This is so, for they have not fully understood the verbal representation of the concept so that it is hard for them to figure out the object's acceleration (Sari et al., 2015). Sutopo et al., (2012) also come at the same finding that the students find it difficult to determine the magnitude and direction of the acceleration. Secondly, the students were still not able to thoroughly understand Newton's Laws I and II and relate them to daily phenomenon. Thirdly, there were some students able to write down the formula correctly, but they made wrong mathematical calculations. Indeed, there were some students who were still not able to understand the basic skill necessary to determine the net force. The students tend to face difficulties in determining the components of the total net force (Sari et al., 2015).

In items No. 5, 6, and 7, the students were able to demonstrate correct verbal representation pertaining to the relationship between force, mass and acceleration in Newton's Law II. However, in items No. 8, 9, and 10, there were many students who still made incorrect mathematical representation. It indicates that the students tend to only memorize how Newton's Law II is articulated, but they do not fully comprehend how it operates. To master concepts in science, it is necessary to comprehend the concept and demonstrate various representations for one concept or the same theme (Murtono et al., 2014). New information transferred by the teacher tends to be only an act of textual memorization for the students, not a meaningful understanding (Sutopo, 2014). A meaningful learning experience occurs when the students are able to relate new learned phenomenon into their cognitive structures in the form of facts, concepts and generalizations they have learned (Zubaidah, et al., 2013a; Zubaidah, et al., 2013b).

The students' understanding of Newton's Law III improved significantly, as seen in the pre-test and post-test scores. It indicates that multi-representation learning is effective to improve the students' comprehension of the concept. Moreover, this research also discovered some difficulties faced by the students in understanding this concept. First, the students did not know what classifies action-reaction forces which mean they did not understand its verbal concept. Secondly, the students merely memorized Newton's Law III, but they still incorrectly related the law to daily phenomena pertinent to the concept of action-reaction forces. The students do not really understand the physical meaning of Newton's Laws, but they tend to only memorize how it is articulated (Malichatin, 2013). It indicates that the new information gained by the students is only an act of textual memorization, not a meaningful understanding (Sutopo, 2014). Thirdly, the students, who were able already to understand what classifies the action-reaction forces, still incorrectly perceived the force-diagrams and determined the pairs of the action-reaction forces. There were still some students who regarded a force whose direction opposite gravity is paired with action-reaction forces. However, there actually is no interaction between those forces. This corresponds with the findings of Zhou et al., (2015) stating that the students face difficulties in deter-mining the pairs of action-reaction forces when it deals with the force of gravity, though they are able to make a good reasoning that the magnitude of action-reaction forces is equal, as postulated in Newton's Law III.

To cope with such difficulties faced by the students, the teacher should give adequate feedbacks so that the students can better understand the concepts and employ them to solve scientific problems. The teacher also should provide various phenomena as in-stances to help the students better relate the concept into daily phenomena.

CONCLUSIONS

From this research, some conclusions can be drawn. Multi-representation learning can significantly improve the students' understanding of Newton's Laws with d-effect size reaching 2.66 (strong) and with N-gain reaching 0.68 (average).

Such learning can reveal the difficulties faced by the students, all of which still appeared in the post-test, in understanding Newton's Law I, II and III. Those difficulties are summarized as follows. With regard to Newton's Law 1, first, the students thought that it is only an object which is not moving that has a net force equal to zero. Such an object is devoid of velocity ($v = 0$) and mass, the motion of which is interrupted as well. Secondly, the students were still not able to differentiate velocity from acceleration. Thirdly, the students thought that it is the mass that causes an object persist its state of motion, not due to the effect of the net force exerted to the object. This occurred as the students did not carefully analyse the force acting on an object. Furthermore, pertaining to Newton's Law II, the students misunderstood the relationship between mass, force and acceleration so that it affected the mathematical representation they made. They also thought that a force exerted to an object will slow down its motion so that they concluded that the net force in Newton's Law II is inversely proportional to an object's acceleration. There were even some students who thought that a force is inversely proportional to an object's mass and a force furthermore affects the object's mass.

With regard to Newton's Law III, there are some difficulties faced by the students. First, the students did not understand what classifies the action-reaction forces. Secondly, though the students memorized Newton's Law III, they still incorrectly related the law to daily phenomena pertinent to the concept of action-reaction forces. Thirdly, there were some students who still perceived that a force whose direction opposite gravity is paired with action-reaction forces though there actually is no interaction between those forces.

Representations constructed by the students improved in terms of the quality. In the pre-test, many of the students' representation quality were placed in Level 0 (missing) and Level 1 (inadequate). However, in the post-test, most of them reached Level 3 (adequate). This improvement indicates that the represen-tations constructed by the students gets more various, logical, complete and correct so that it is easier for them to analyse and understand a problem.

It is suggested that science teachers need to sufficiently give feedbacks to the students who face the aforementioned difficulties. This is so, for it enables them to solve the science problems. In applying the multi-representation learning, the teachers are supposed to improve their multi-representation skills so that the learning can be maximized. Moreover, for future researchers, they have to prepare questions for interviews in details so that the change in the students' reasoning can be better monitored. Items designed to elicit the students' comprehension about the concept should be able to make all kinds of representations appear so that the students can demonstrate various representations in solving the problems.

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