K-10 students’ conceptual understanding on Newton's laws: current and future directions

I M Hermanto*, M Muslim, A Samsudin and J Maknun
Program Magister Pendidikan Fisika, Universitas Pendidikan Indonesia, Bandung, Indonesia.

*Corresponding author’s email: imadehermanto@upi.edu

Abstract. The aim of this research to obtain a profile of K-10 students' conceptual understanding on Newton's laws. In fact, not only student conceptual understanding is at a low level but also high-order thinking skills. This research is qualitative research with a case study method and using embedded, single-case design. Moreover, students' conceptual understanding is measured based on indicators explaining, comparing, inferring and interpreting. This research has already implemented to K-10 students (13 male and 21 female students) in Bandung. The results report that students' conceptual understanding for each indicator was such as explaining, comparing, inferring and interpreting is generally insufficient category. It can be concluded that students' conceptual understanding on Newton's law is still low.

1. Introduction
Physics is one of the sciences that in the learning process emphasizes conceptual understanding. When learning about physics, it will not be separated from the essential concepts that exist in every material. So that understanding of the concept becomes very important to be able to study physics in its entirety and be scientifically correct. One important concept in physics is Newton's laws which is a fundamental concept of the motion of objects related to force and mass. This law was formulated by Isaac Newton into three basic laws. Newton's first law is the law of motion in physics which explains the motion of an object related to the nature of laziness (the nature of its inertia).

Newton's second law describes the state of an object when the force acts (one or more) on the object, where the object will have an acceleration proportional to the net force that acting it and is inversely proportional to the mass of the object itself when observed in the same inertial frame [1].

\[ \Sigma F = ma \]  \hspace{1cm} (1)

Newton's third law is a law of motion that explains the pair of action-reaction forces that occur in two different objects interacting. It turns out that the two objects will work on each other with the same force and the opposite direction. Newton's third law basically explains that a single force is impossible to form, and the force that appears will always be in pairs. The illustration for the pair of action-reaction force that occurs in two different objects is shown in figure 1.

\[ F_{12} = -F_{21} \]  \hspace{1cm} (2)
The two forces acting on one object even though the magnitude is the same and the opposite direction is not a pair of action-reaction forces. In Newton's law material there are several fundamental concepts that students must understand related to mass, force, and acceleration. For this reason, learning must facilitate students to do concept learning activities.

Concept learning activities are learning to develop logic inference or generalize from facts to concepts. The concept is a general idea or understanding that is arranged with words, symbols, and signs. The concept can be interpreted as a network of relationships in the object of the incident, and others that have permanent characteristics and can be observed. The concept contains things that are common from a number of objects and events. By learning concepts students can understand and distinguish objects, events, and events that exist in the surrounding environment [2]. The ability of students to understand a concept scientifically makes students easier to apply the concept to solve a problem. However, until now the understanding of students' concepts in physics is still a special concern for researchers.

Previous research shows that students still have difficulty understanding concepts in physics. Some of them show results that students still have difficulty learning physics which is caused by low mastery of concepts [3-4]. Students still experience serious conceptual and reasoning difficulties for mechanical material [5]. Students also experience difficulties in understanding the concept of energy [6]. Other research results [7] show that students still experience difficulties in understanding the net force concept and applying it to Newton's law. Most of the low understanding of students' concepts occurs in mechanical materials based on Newton's laws. The low conceptual understanding of students' will be very influential when students want to develop high-level thinking skills. With low-level basic thinking skills, students will also have difficulties in developing high-level thinking skills. Therefore, it is necessary to conduct case study research to identify students' conceptual understanding of Newton's laws.

2. Methods

2.1 Participant
K-10 students who are in the same lesson have been carefully chosen as participants in this research. They amount to 34 students (13 male and 21 female) with ages between 15 and 16 years old. The school where participants learn is a school that is under the auspices of the Military Foundation and greatest of the participants are families of a soldier. Grounded on the outcomes of observations and discussions with teachers, schoolrooms where students learn to have good facilities to sustenance the learning process in the classroom.

2.2 Instrument
Fifteen questions around Newton's law concepts in the form of multiple-choice tests were used as instruments in this research. Indicators of the ability to understand (interpreting, inferring, comparing and explaining) referring to the revised Bloom Taxonomy, were selected as indicators to develop a conceptual understanding test. Test validation has been carried out by experts and reliability tests have been tested for reliability and it was initiated that the test had the reliability of 0.74 with a high category. The distribution of questions based on each understanding indicator in the test is shown in table 1 below.
Table 1. The distribution of questions based on each indicator of understanding.

| The Indicator of Understanding Ability | Description of Understanding Ability Indicator | Quantity of Questions | Questions Number |
|---------------------------------------|-----------------------------------------------|-----------------------|------------------|
| Explaining                            | able to create and use a causal model in a system. | 5                     | 1, 2, 9, 14, 15  |
| Interpreting                          | able to change information from one form to another. | 2                     | 6, 12            |
| Comparing                             | able to search one-on-one correspondences between elements and patterns in one object, phenomena, or another idea. | 6                     | 3, 5, 7, 10, 11, 13 |
| Inferring                             | able to abstract a concept or principle that explains these examples by looking at the characteristics of each example and, most importantly, by drawing relationships between these characteristics. | 2                     | 4, 8             |

On the other hand, understanding tests are also adapted to the concepts contained in the lesson of Newton's law. Hence 15 questions in the conceptual test have represented concepts that exist in Newton's laws. Figure 2 below shows one example of the question in the conceptual understanding test on Newton's third law.

2.3 Research Design
This research is qualitative research with a case study method to determine the ability of students' conceptual understanding of Newton's law. The case study design used is an embedded, single-case design, where one way to increase sensitivity to ever-changing research orientation is to have a set of sub-units. The sub-units can often enhance significant opportunities for extensive analysis, attractive the understandings into the single case. Thus, an embedded design can attend as an important device for focusing on case study investigations [8]. K-10 students are selected as sub-units of this research with a single case focus on students conceptual understanding. K-10 students were selected on the grounds that
they had just finished learning about Newton's law. Students' conceptual understanding is measured by giving Newton's law conceptual understanding test. The time given to complete the understanding test is 2 hours of lesson, in which 1 hour of the lesson is 45 minutes. Furthermore, the results obtained by students were analyzed using a percentage interpretation and analyze the factors that directed to the low conceptual understanding of students in Newton's laws grounded in the literature review in previous research.

3. Result and Discussion

Data analysis that has been completed for students' answers to the test conceptual understanding of Newton's laws gives results as shown in figure 3 below.

![Figure 3. Results of Student Conceptual Understanding Test.](image)

Figure 3 shows that the average conceptual understanding of students is still in the low category. However, if viewed based on indicators of understanding the concept there are differences in each indicator. The lowest students' conceptual understanding is in the indicators explaining. The indicator explains that there is one question number 15 which is only answered correctly by one student and there is one question number 14 whose answer is wrong for all students.

Although the difficulty level of questions number 14 and 15 are included in the medium category, these result confirmations that students still have problems in solving the questions in the indicator explaining. In question number 14 students have not been able to explain the relationship between Newton's I law with regular straight motion when an object moves on a slippery trajectory. Whereas for question number 15 students have not been able to explain how the object acceleration when the constant force acting on an object. On questions with other indicators explaining, students also get a low score.

The subsequent indicators of conceptual understanding that falls into the low category are the indicators inferring. There is one question number 8 which only two students answered correctly. Question number 8 has a difficulty level with the medium category and is related to the gravity concept associated with the radius of the earth. The results obtained also show that students' ability to inferring the weight relationship of objects with the radius of the earth is still low. Students have not been able to understand that the earth is an ellipse in which in the polar region the radius of the earth is smaller than the region of the equator.

The subsequent indicators of conceptual understanding that fall into the low category are the indicators comparing. There are two questions number 11 and number 13 whose answers are wrong for all students. This can be caused by the difficulty level of the two questions in the difficult category. In addition, these two questions are related to the concept of Newton's third law, specifically the action-reaction force of two objects with different masses and velocities. These results show that students' conceptual understanding on the pair of action-reaction force is still low. Especially for cases in two
objects that have different masses and two objects that have different velocities. Conceptual understanding indicators that included in the medium category and having the highest percentage of the average score are the interpreting indicators. Although on average the percentage of the score was in the medium category, there was one problem number 12 where only three students answered correctly.

The question is also related to Newton's III law concept of action-reaction force pairs. This is in accordance with the problems in comparing indicators, where students' conceptual understanding of Newton's III law is motionless low. Based on these results, it can be seen that students still experience the greatest difficulties in Newton's III law. This student difficulty can be caused by students' difficulties in visually determining the pair of action-reaction forces that are specifically related to free body diagrams. The difficulty that many student’s involvements are understanding free body diagrams, and in particular, using these diagrams to determine the net force and student’s confusion to visually compare the total force on objects [9]. This difficulty can also be caused by an understanding that has been attached to students about a phenomenon in everyday life. Students’ understanding of phenomena that occur in everyday life is often not in accordance with scientific concepts to explain the phenomenon. Students still tend to maintain their intuitive conception, even adding other concepts that are not scientific [10].

The difficulty of students in understanding Newton's law will certainly have an impact on students' difficulties in understanding the next material. Like the results of the study [11], which shows that students experience difficulties in establishing the relationship between kinematics and fluid dynamics, especially the discussion of the interaction of forces in accordance with Newton's law. Difficulties can be overcome through demonstration activities in the learning process, where students can interact directly with an object to be able to feel the action-reaction force. This activity can provide real-life experiences for students, making learning more meaningful and making students have a better understanding of Newton's third law [12]. On the other hand, physics learning that is taught in a fast way turns out to have less impact on students' conceptual understanding. Sometimes physics material must be taught slowly for the better conceptual understanding of students. This does not mean that the material studied must be less than the material contained in the curriculum [13]. To anticipate this time problem, discussion activities can be a choice in learning. Besides that, interactions that occur in discussion activities (interactions between teachers and students, between students and students and between groups) can actually train students' conceptual understanding [14-17].

The difficulty of students in understanding the concepts in learning is certainly inseparable from the learning methods used. Traditional methods commonly applied in learning are apparently not good enough to overcome certain conceptual difficulties experienced by students. This fundamental difficulty must be dealt with specifically, where students use their intellectual abilities actively in learning through giving challenges in different contexts [18]. One method of learning that can train students' understanding of physics concepts in the material of Newton's law is to use visual learning [19,20]. So that it becomes important in subsequent studies to apply to learn in visual form as a determination to enhance students' conceptual understanding of physics material.

4. Conclusion
When learning about physics it will not be separated from the essential concepts that exist in every physics lesson. Therefore, the understanding of concepts in physics becomes very important to be able to learn physics in its entirety and in accordance with scientific concepts. Grounded on the results of the research, hence that the average conceptual understanding of K-10 students on Newton's law material is still in the low category. But for each indicator understanding the concept has an average score varies. The order of conceptual understanding indicators from the lowest to the highest is, the explaining indicators, inferring indicators, comparing indicators, and interpreting indicators. Related to the Newtons law concepts, students' lowest conceptual understanding is found in Newton's III law material related to the relationship of the action-reaction force between two objects. The confines of this study are the insignificant number of samples. So that the results of this study only show the profile of students' conceptual understanding in the class that is the research sample. For that to obtain results that can be generalized widely, it is recommended to conduct further research with a larger sample size. On the
other hand, further research is needed to improve students' conceptual understanding on Newton's law by applying contextual visual learning.

5. References

[1] Serway A R and Jewett J J W 2008 Physics for Scientists and Engineers with Modern Physics (USA: Thomson Learning, Inc)

[2] Thobroni M and Mustofa A 2013 Belajar dan Pembelajaran: Pengembangan Wacana dan Praktik Pembelajaran Dalam Pembaruan Nasional (Jogjakarta: AR-RUZZ MEDIA)

[3] Khoirul A M, Langlang H and Pratiwi D 2012 Identifikasi Kesulitan Belajar Fisika Pada Siswa RSBI: Studi Kasus di RSMABI Se Kota Semarang Unnes Physics Education Journal 1 2 5-10

[4] Rusilowati A 2006 Profil Kesulitan Belajar Fisika Pokok Bahasan Kelistrikan Siswa SMA di Kota Semarang Jurnal Pendidikan Fisika Indonesia 4 2 100-106

[5] Bradley S A 2004 Investigating student understanding in intermediate mechanics: Identifying the need for a tutorial approach to instruction American Journal of Physics 72 4 453 – 459

[6] Park M and Liu X 2015 Assessing Understanding of the Energy Concept in Different Science Disciplines Science Education 100 3 483–516

[7] Singh C and Schunn C D 2016 Connecting Three Pivotal Concepts in K-12 Science State Standards and Maps of Conceptual Growth to Research in Physics Education (Pittsburgh: University of Pittsburgh)

[8] Robert Y 2014 Case study research: design and methods (USA: Sage Publications, Inc)

[9] Stefanie A W and Jessica D G 2015 Diagnostic Opportunities Using Rasch Measurement in the Context of a Misconceptions-Based Physical Science Assessment Science Education 99 4 721–741

[10] Lemmer M 2013 Nature, Cause and Effect of Students’ Intuitive Conceptions Regarding Changes in Velocity International Journal of Science Education 35 2 239-261

[11] Suarez A, Kahan S, Zavala G and Marti A C 2017 Students’ conceptual difficulties in hydrodynamics Physical Review Physics Education Research 13 2 1-12

[12] Bao L, Hogg K and Zollman D 2002 Model analysis of fine structures of student models: An example with Newton’s third law American Journal of Physics 70 7 766-778

[13] Bigozzi L, Tarchi C, Falsini P and Fiorentini C 2014 ‘Slow Science’: Building scientific concepts in physics in high school International Journal of Science Education 36 13 2221-2242

[14] Bungum B, Bøe M V and Henriksen E K 2018 Quantum talk: How small-group discussions may enhance students’ understanding in quantum physics Science Education 1 2 856-877

[15] Murphy P K, Greene J A, Allen E, Baszczewski S, Swearingen A, Wei L and Butler A M 2018 Fostering high school students’ conceptual understanding and argumentation performance in science through Quality Talk discussions Science Education 102 6 1239-1264

[16] Wade-Jaimes K, Demir K and Qureshi A 2018 Modeling strategies enhanced by metacognitive tools in high school physics to support student conceptual trajectories and understanding of electricity Science Education 102 4 711-743

[17] Dega B G, Kriek J and Mogese T F 2013 Categorization of Alternative Conceptions in Electricity and Magnetism: the Case of Ethiopian Undergraduate Students Research in Science Education 43 5 1891–1915

[18] McDermott L C 1997 Students’ Conceptions and Problem Solving In Mechanics Connecting Research in Physics Education with Teacher Education 42-47

[19] Thornton R K and 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

[20] Sornkhatha P and Srisawasdi N 2013 Supporting Conceptual Development in Newton’s Laws of Motion using an Interactive Computer-Simulated Laboratory Environment Proceedings of Social and Behavioral Sciences 93 2010–2014