# COLLEGE STUDENTS' CONCEPTIONS OF NEWTONIAN MECHANICS: A CASE OF SURABAYA STATE UNIVERSITY INDONESIA[1)]

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**Abstract.** Students' understanding of scientific phenomena have been of considerable interest to science education researchers. However, students' conceptions might differ from those generally accepted by researchers as scientific concepts. This study was possessed the conception profile of college students in mechanics by using: Force Concept Inventory (FCI) and Mechanics Baseline test (MBT). The study identified the concept of supporting the cause of misconceptions. A descriptive quantitative approach was used, which included 90 college physics students at Surabaya State University as the participants. The results indicated that, *first,* students' conceptions on Newtonian mechanics based on FCI performed that students at Junior level better than Sophomore and Freshman. *Second*, the overall level of misconception among college students was moderate (68.86%). The two highest levels of misconception were kinds of force with fluid contact (81.67%) and Newton's second law (78.33%). *Third*, according to MBT, college students have a very low understanding regarding the kinds of acceleration, kinematics, energy conservation, superposition force, action-reaction, and free fall. *Last*, the overall level of misconception among college students was high (75.91%). The highest levels of misconception were the topics of kinematics; both centripetal and average acceleration (86.67% and 85.56%, respectively). The students also performed high level in misconception in general principles (such as, energy conservation, superposition of force, free fall, and action-reaction).

*Keywords:* Newtonian mechanics, conception, FCI, MBT

## Introduction

For the past three decades, students' understanding of scientific phenomena have been of considerable interest to science education researchers and science teachers. As students learn about the world surrounding them formally through school or their everyday experiences. However, their perception based on this situation created their own conception. Students' conceptions might differ from those generally accepted by researchers as scientific concepts. Some scholars have used different terms to represent the students' conception such as 'preconceptions' (Novak, 1977), 'misconceptions' (Clement et al., 1989; Helm, 1980), 'alternative framework' (Klammer, 1998; Driver, 1981), 'children's science ideas' (Osborne et al., 1993; Gilbert et al., 1982), 'mental models' (Greca & Moreira, 2002), 'tacit knowledge and children's conceptions' (Taber, 2013; Collins, 2010), and so forth.

For those students' conception in science, physics was the main disciplined examined (Chiu et al., 2016). Therefore, there were some diagnostic instruments to identify the students' conception in physics domain (e.g., Force Concept Inventory by Hestenes et al. (1992); Mechanic Baseline Test by Hestenes & Wells (1992); Energy and Momentum Conceptual Survey by Singh & Rosegrant (2003); Diagnosing and Interpreting Resistor Circuits by Engelhardt & Beichner (2004), etc.).

According to the constructivist learning theory, students come to class with the misconceptions which they shape up as a result of their interaction with the world. These misconceptions are affected by students' way of interpreting and constructing new concepts (Boo & Watson, 2001). The pre-idea that being held by students are firm and not easily changeable although the scientific concept has been provided (Sencar & Eryilmaz, 2004). This statement highlights teachers' role of detecting the misconceptions that exist between students and take precaution steps and alternatives in order to curb the phenomenon of misconceptions. Therefore, it is very important for a pre-service teacher not to have any misconceptions as is it will be inherited by their students.

The researchers believed that one study should be conducted to identify the misconception among college students as their role as pre-service teacher. Thus, the study was preliminary studies of conception possessed profile college student in mechanics using instruments: Force Concept Inventory (FCI) and Mechanics Baseline test (MBT), and identified the concept of supporting the cause of misconceptions. In order to answer the problem statement, researchers had developed a few research objectives which are to determine: (a) the level of misconceptions on Newtonian mechanics among college students, according to Force Concept Inventory (FCI) and (b) the level of misconceptions on Newtonian mechanics among college students according to Mechanics Baseline test (MBT).

**Methodology**

Participants of the study included 90 college physics students at Surabaya State University, Indonesia, which thirty (30) students for each level (Freshman, Sophomore, and Junior). The research used a descriptive quantitative approach by using instruments: FCI and MBT. The FCI instrument developed by Hestenes et al. (1992).[2)] The MBT instrument created by Hestenes & Wells (1992) and translated to Indonesia version by the first researcher. A data collection technique used written test (paper and pencil test) by providing instruments FCI and MBT, which consisted 30 items and 26 items, respectively. Data analysis used descriptive analysis of the percentage to determine the student's conception of each item problem. The marking scheme made for the correct answers was one marks, and for incorrect answers zero marks were given. Next, from the calculation of the percentage of conception, can be identified the possibility of misconceptions on the basic physics concept. The percentage of misconception for every subtopics of the Newtonian concept was obtained by dividing the marks of the incorrect answers with the total items. The percentage of misconceptions for each item were compared to the misconception division level (Table 1). All data collected were analyzed descriptively and were presented in mean (average) and percentage.

**Table 1.** Misconception division level

| Percentage | Level of misconception |
|---|---|
| 85-100 | very high (VH) |
| 70-84 | high (H) |
| 55-69 | moderate (M) |
| 40-54 | low (L) |
| 0-39 | very low (VL) |

Azman et al. (2013)

**Results**

Based on the results of student responses to the FCI instrument, the data were processed to obtain the following percentage of student truly conception (Table 2).

**Table 2.** Students' truly conception of each FCI item

| Item | Students conception (%) | | | Physics concept | subtopics |
|---|---|---|---|---|---|
| | J | S | F | | |
| 1 | 70* | 40 | 10 | Acceleration independent of weight | Kinds of force: Gravitation |
| 2 | 100* | 20 | 0 | Acceleration independent of weight | Kinds of force: gravitation |
| 3 | 30 | 20 | 30 | Acceleration independent of weight | Kinds of force: gravitation |
| 4 | 70* | 0 | 30 | Impulsive force | Thirds law |
| 5 | 40 | 30 | 0 | Buoyant (pressure) | Kinds of force: fluid contact |
| 6 | 50* | 50* | 60* | First law: with no force | First law |

| Item | Students conception (%) | | | Physics concept | subtopics |
|---|---|---|---|---|---|
| | J | S | F | | |
| 7 | 70* | 70* | 40 | First law: with no force | First law |
| 8 | 10 | 10 | 30 | Second law: impulsive force | Second law |
| 9 | 40 | 40 | 20 | Second law: impulsive force | Second law |
| 10 | 60* | 20 | 20 | First law: speed constant | First law |
| 11 | 20 | 0 | 20 | Gravitation | Kinds of force: Gravitation |
| 12 | 90* | 70* | 30 | Parabolic trajectory | Kinds of force: Gravitation |
| 13 | 0 | 0 | 0 | Gravitation | Kinds of force: Gravitation |
| 14 | 50* | 50* | 10 | Parabolic trajectory | Kinds of force: Gravitation |
| 15 | 40 | 60* | 30 | Third law: for continuous forces | Third law |
| 16 | 90* | 40 | 50* | Third law: for continuous forces | Third law |
| 17 | 60* | 0 | 0 | Cancelling forces | Superposition principle |
| 18 | 60* | 40 | 0 | Gravitation | Kinds of force: Gravitation |
| 19 | 60* | 50* | 10 | Velocity discriminated from position | Kinematics |
| 20 | 70* | 40 | 0 | Accelerated discriminated from velocity | Kinematics |
| 21 | 20 | 0 | 40 | Second law: constant acceleration | Second law |
| 22 | 20 | 20 | 10 | Constant acceleration entails; changing speed | Second law |
| 23 | 10 | 0 | 20 | First law: velocity direction constant | First law |
| 24 | 40 | 50* | 40 | First law: speed constant | First law |
| 25 | 60* | 60* | 10 | Cancelling force | Superposition principle |
| 26 | 10 | 10 | 10 | Cancelling force | Superposition principle |
| 27 | 30 | 10 | 30 | Friction opposes motion | Kinds of force: Solid contact |
| 28 | 70* | 40 | 20 | Third law: for impulsive force | Third law |

| Item | Students conception (%) | | | Physics concept | subtopics |
|---|---|---|---|---|---|
| | J | S | F | | |
| 29 | 70* | 70* | 40 | Third law: for impulsive force | Third law |
| 30 | 20 | 0 | 20 | Air resistance | Kinds of force: fluid contact |
| Average | 47.67 | 30.33 | 21.00 | | |

*(Note: J = Junior, S=Sophomore, F= Freshman; * the percentage of students conception at least 50%)*

The asterisk sign (*) on Table 2 indicates the percentage of students conception at least 50%. In general, most students performed very lacking in understanding of the all of the key concepts (less than 50%), except number 6 (Newton's first law with no force). Overall, student's conception on Newtonian mechanics based on FCI in Junior level better than Sophomore and Freshman. The average conception was 47.67%, 30.33%, and 21.00%, respectively. At FCI, the interval difference of the FCI's conception between Junior and Sophomore was approximately 17%, then 9% between Sophomore and Freshman. The possibility reason was the level of course's material in Junior has been very much and already took a mechanic-course. Therefore, they have more mature understanding of the concepts of Newtonian. Sophomore's student only still armed with the knowledge of basic physics from the first year, yet have mastery of the material as much as the student in Junior, so that the lower of the conception level. However, Freshman students only used their knowledge from senior high school. This situation also consisted with their cognitive level, which will automatically owned conception would be better than the previous age.

**Table 3.** The level of Misconceptions among college students based on FCI

| Concept | Percentage (%) | | | | Level of Misconception |
|---|---|---|---|---|---|
| | J | S | F | Average | |
| Kinematics | 35 | 45 | 95 | 58.33 | M |
| Newton's First Law | 54 | 62 | 64 | 60 | M |
| Newton's Second Law | 77.5 | 82.5 | 75 | 78.33 | H |
| Newton's Third Law | 32 | 58 | 66 | 52 | L |
| Superposition Principle | 56.67 | 76.67 | 93.33 | 75.56 | H |
| Kinds of Force: | | | | | |
| Solid contact | 70 | 90 | 70 | 76.67 | H |
| Fluid contact | 70 | 85 | 90 | 81.67 | H |
| Gravitation | 47.5 | 70 | 87.5 | 68.33 | M |
| Average | | | | 68.86 | M |

*(Note: J = Junior, S=Sophomore, F= Freshman; L=low, M=moderate, H=high)*

Based on the Table 3, the overall level of misconception among college students on the subtopic of force and motion based on FCI instrument was moderate (68.86%). The highest levels of misconception are the subtopic of kinds of force with fluid contact (81.67%), Newton's second law (78.33%), kinds of force with solid contact (76.67%), and the superposition principle (75.56%). At the moderate level of misconceptions the subtopic kinds of force: gravitation (68.33%), Newton's first law (60%), and kinematics (58.33%). However, college students performed better in Newton's third law with low level of misconception (52%).

Regarding the kinds of force with fluid contact and solid contact, students confused regarding the passive, impulsive and friction opposes motion. In addition, the concept of air resistance and buoyant (air pressure) also stood at the same situation as well as gravitation at the moderate level. Gravitation as part of kinds of force, students believed that air pressure contributes to gravity. The net force due to air pressure is actually upward (buoyant force) instead of downward, was hardly recognized by students (Hestenes et al., 1992).

Turning to the Newton second law, a particle will change its state of motion when it is acted on by an external force or active force. This law gives a specific way of determining how a body's motion is changed by an external applied force: the particle's time rate of change of momentum is equal to the externally applied force and takes place in the direction in which the force acts (Chow, 2013). Many students did not understand about the existence of active force. As Hestenes et al. (1992) underlined that this force is causal agents—they have the power to cause motion—to create the impetus and transfer it to other objects.

The next topic with high level of misconception is the superposition. When talking about superposition, the point of focus is on vector sum and cancelling forces. Vector sum and cancelling forces are being discussed in the subtopic of analyzing forces in equilibrium. Hestenes et al. (1992) stated that the common misconceptions regarding the superposition principle are that respondents tend to get confused with the action/reaction pair with the superposition of oppositely directed forces on a single object. This resolves that, respondents are applying a direct common sense of thinking as they unable to differentiate between two concepts.

Newton's First Law states that if there is no force acting on a body, its state of motion will be unchanged. For Newton's first law, many got uncertain about the definition and holds on common mistake by understanding that "if no net force acts on an object, the object must be at rest". Relating to this confusion, common sense thinkers come out with two kinds of force, which known as impetus and active force. 'Impetus' was introduced back in the pre-Galilean times, which refers to 'motive power' or 'intrinsic force' that keeps things moving (Hestenes et al., 1992). This common sense totally disagreed with Newton's First Law. Impetus theory, describes about the force that acts on an object. As a force acts on an object, the object gains a property called impetus. Although the force is not in contact with the object, the impetus remains in the object and keeps the object moving. As time passes, impetus decreases because of the resistance of medium or opposing forces and causes the object to come to a rest. This idea was propounded by one of the fifth-century philosophers, Philoponus, to explain projectile motion. These types of imaginative forces are used to explain projectile motion and motion of objects thrown upward. Referred to the impetus idea, some students also believe that gravity does not act until the impetus wears down. A research done by Azman et al. (2013) also showed a high level of misconceptions, especially in the Newton's First Law concept among the physics pre-services teachers in Malaysia.

As for kinematic topic, the high percentage of misconceptions of kinematics showed that respondent unable to differentiate between three vital concepts which are position, velocity, and acceleration. In fact, the Force Concept Inventory succeeds in reflecting the ability of the university student in recognizing the vectorial nature of velocity and acceleration (Hestenes et al., 1992). A research done by Bayraktar (2009) also showed similarities with this research findings as the level of misconceptions among the pre-services teachers of Turkey were high.

At the low level, students confused about action reaction pairs. These findings in-lined with Bayraktar (2009) who found that student-teachers' conceptions about Newton's Third Law, on the other hand, were significantly better than those observed in other research done in other countries such as the US and Finland. Students often interpret the term " interaction" by a "conflict metaphor". The authors interpreted this result to imply that many students have difficulty in generalizing Newton's Third Law to cover accelerated and uniform velocity cases both, and that, many students believe that Newton's Third Law hold only in dynamic conditions. Difficulties in students' understanding of Newton's Third Law were observed in numerous other research studies as well. For example, Yeo & Zadnik (2000), who used several questions of the FCI as part of their test to detect students' difficulties in understanding force and motion.

**Table 4.** Student's conception of each MBT item

| Item | Students conception (%) | | | Physics concept | |
|---|---|---|---|---|---|
| | J | S | F | | |
| 1 | 50* | 40 | 10 | constant acceleration | CA |
| 2 | 50* | 30 | 10 | constant acceleration | CA |
| 3 | 20 | 10 | 10 | constant acceleration | CA |
| 4 | 70* | 70* | 20 | tangensial acceleration | TA |
| 5 | 20 | 0 | 30 | normal acceleration | NA |
| 6 | 50* | 20 | 60* | free fall | FF |

| | | | | | |
|---|---|---|---|---|---|
| 7 | 10 | 0 | 20 | superposition of force | SF |
| 8 | 30 | 10 | 10 | normal acceleration | NA |
| 9 | 40 | 0 | 0 | centripetal acceleration | SA |
| 10 | 10 | 0 | 20 | Energy conservation | EC |
| 11 | 50* | 20 | 10 | Energy conservation | EC |
| 12 | 10 | 0 | 30 | action-reaction | AR |
| 13 | 30 | 50* | 10 | action-reaction | AR |
| 14 | 70* | 40 | 10 | action-reaction | AR |
| 15 | 0 | 60* | 30 | momentum conservation | MC |
| 16 | 10 | 40 | 10 | Impuls-momentum | MC |
| 17 | 10 | 10 | 10 | average acceleration | AA |
| 18 | 0 | 20 | 20 | average acceleration | AA |
| 19 | 10 | 10 | 10 | superposition of force | SF |
| 20 | 20 | 0 | 10 | work-energy | EC |
| 21 | 60* | 60* | 30 | momentum | MC |
| 22 | 50* | 60* | 20 | Impuls-momentum | MC |
| 23 | 30 | 30 | 0 | average acceleration | AA |
| 24 | 40 | 0 | 10 | integrated displacement | ID |
| 25 | 30 | 40 | 20 | average velocity | AV |
| 26 | 10 | 20 | 20 | free fall | FF |
| Overall | 30.00 | 24.62 | 16.92 | | |

*(Note: J = Junior, S=Sophomore, F= Freshman; * the percentage of students conception at least 50%)*

Table 4 presents that the respondents have a very low understanding regarding the basic concepts regarding kinematics: the kinds of acceleration, energy conservation, superposition force, action-reaction, and free fall. From all the basic concepts, supporting the concept actually involved is the mass, velocity, force, and acceleration. If connected with the concept of supporting experiencing misconceptions on the instrument FCI and MBT, then the concept of support that is not well understood is the concept of speed and acceleration. If this support concept can be inferred, then students will not experience an error or even do not know the concept when faced with questions which contains the basic concepts. Unlike the FCI, some computation is required in MBT, so students use more time in MBT than FCI (Antwi et al., 2011). The two tests

(FCI and MBT) are complementary probes for understanding of the most basic Newtonian concepts.

A fairly low percentage of the conception of the three groups of respondents on average range in the range of 16% - 30%. It is not much different of the FCI instrument (21%-48%). Students' conception in responding MBT instrument can be said to be very less, compared with the results on the instrument FCI. Table 4 also shows the average conception was 30.00%, 24.62%, and 16.92% for Junior, Sophomore, and Freshman, respectively. At MBT, the interval difference of the MBT's conception between Junior and Sophomore was approximately 6% and 8% between Sophomore and Freshman. The possibility reason was the same as well as the conception to FCI aforementioned.

**Table 5.** The level of Misconceptions among college students based on MBT instrument

| Concept | Percentage (%) | | | | Level of Misconception |
|---|---|---|---|---|---|
| | J | S | F | Average | |
| Kinematics | | | | 75.28 | H |
| Linier motion: | | | | 78.33 | H |
| Constant acceleration (CA) | 60 | 73.33 | 90 | 74.44 | H |
| Average acceleration (AA) | 86.67 | 80 | 90 | 85.56 | VH |
| Average Velocity (AV) | 70 | 60 | 80 | 70.00 | H |
| Integrated Displacement (ID) | 60 | 100 | 90 | 83.33 | H |
| Curvilinier motion | | | | 72.22 | H |
| Tangensial acceleration (TA) | 30 | 30 | 80 | 46.67 | L |
| Normal acceleration (NA) | 75 | 95 | 80 | 83.33 | H |
| Centripetal acceleration (SA) | 60 | 100 | 100 | 86.67 | VH |
| General Principles | | | | 76.32 | H |
| Superposition of force (SF) | 83.33 | 80 | 86.67 | 83.33 | H |
| Energy Conservation (EC)<br>Energy conservation<br>Work- energy | 73.33 | 93.33 | 86.67 | 84.44 | H |
| Action – reaction (AR) | 60 | 80 | 80 | 73.33 | H |
| Momentum conservation (MC)<br>Momentum conservation<br>Impuls- momentum | 70 | 45 | 77.5 | 64.17 | M |
| Specific Forces | | | | 73.33 | H |
| Free Fall (FF) | 70 | 80 | 70 | 73.33 | H |
| Average | | | | 75.91 | H |

*(Note: J = Junior, S=Sophomore, F= Freshman; L=low, M=moderate, H=high, VH=very high)*

Table 5 describes the overall level of misconception among college students based on MBT instrument was high (75.91%). The highest levels of misconception were the topics of kinematics; both centripetal and average acceleration (86.67% and 85.56%, respectively). The other concepts in general principles (such as: energy conservation, superposition of force, free fall, and action-reaction), students also performed high level in misconception. At the moderate level of misconceptions, students indicated 64.17% misconception in momentum conservation. However, college students performed better in tangensial acceleration with low level of misconception (46.67 %).

**Discussion**

The findings of this study depict that students' conceptions on Newtonian mechanics based on FCI instrument are very low. The overall level of misconception among college students on the subtopic of force and motion based on FCI instrument was moderate (68.86%). The highest levels of misconception are the subtopic of kinds of force with fluid contact (81.67%), Newton's second law (78.33%), kinds of force with solid contact (76.67%), and the superposition principle (75.56%). In addition, college students also have a very low understanding regarding the basic concepts of the kinds of acceleration, kinematics, energy conservation, superposition force, action-reaction, and free fall by using MBT. The overall level of misconception among college students based on MBT instrument was high (75.91%). The highest levels of misconception were the topics of kinematics; both centripetal and average acceleration (86.67% and 85.56%, respectively). The other concepts in general principles (such as, energy conservation, superposition of force, free fall, action-reaction, and kinematics), students also performed high level in misconception. All these findings also in-lined with the following previous researches: (i) *Confusion of position and velocity, and velocity and acceleration*: students sometimes believe that there is a linear relationship between force and velocity (instead of force and acceleration). They expect a constant velocity from a constant force. When two objects are in the same position, students think that the velocities are the same (Bayraktar, 2009); (ii) *Heavier objects fall faster*: students believe that heavier objects fall faster than lighter ones (McDermott, 1984; Hestenes et al., 1992; Bayraktar, 2009; Luangrath et al., 2011); (iii) *Impetus idea*: students believe that, when a force acts on an object, the object gains, what is called, impetus. When the force does not act on the object any longer, the impetus is thought to remain but to diminish. The object continues to move until the initial "force" (impetus) is used up (Hestenes et al., 1992; Bayraktar, 2009), some students also believe in a circular impetus; (iv) *Motion implies force*: students think that a force is needed to keep an object moving. As a consequence, they think that it should be a force in the direction of motion (McDermott, 1984; Jimoyiannis & Komis, 2003; Bayraktar, 2009; Luangrath et al., 2011); (v) *Dominance idea*: students often interpret interaction via a conflict metaphor, where strength is attributed to those who are bigger, heavier, or more active. Objects with greater mass, or a more active object, is thought to exert a greater force (Bayraktar, 2009; Luangrath et al., 2011); (vi) *Action-reaction pairs act on the same object*: students think that the objects could be balanced in this way (Reach, 1992; Jimoyiannis & Komis, 2003).

In the current study, researchers only highlighted in the discussion of the level of understanding among college students on the physics concepts of force and motion in general by using FCI and MBT. The implication for college student as well as the pre-services teachers are those who are in the first row that will shape the future of the next generations, it is highly recommended in applying the style of teaching and learning on a more conceptual understanding as it can help in curbing the misconceptions phenomenon among the pre-services teachers. This is because the approach in the form of conceptual understanding can help pre-services teachers themselves learn physics concepts in a realistic and accurate understanding. The following step is to apply appropriate teaching methods to overcome the misconceptions. Tests for diagnosing the misconceptions such as the FCI, MBT, or various questioning techniques could be used in the process. Research related to misconceptions has shown that traditional teaching methods are not really effective in overcoming misconceptions (Saul & Redish, 1998). Suggested methods generally include interactive and constructive methods such as computer assisted instruction (Bernhard, 2000; Tao & Gunstone, 1999), and a variety of cooperative learning (Saul & Redish, 1998).

In addition, to improve the understanding of physics concepts we suggested that lecturers should implement teaching style of various situations, so that it can help pre-services teachers apply the concepts they learned and provide explanations for each of their answers for every concept questions. As Antwi et al. (2011) suggested that the interactive engagement (IE) approaches have a significant impact on students' scores in both FCI and MBT. Some approaches like concept quiz, think-share present, conceptual and reasoning questions, group discussion, and tutorials were used in all the lessons (Hake, 1998). This could suggest that IE approaches could effectively improve students' conceptual understanding and insightful problem solving in mechanics. Moreover, for helping researchers to portray the students' reasoning behind their answers, two-tier test or three-tier test of mechanics can be considered.

## Conclusion

There were some conclusions of the study. *First*, student's conception on Newtonian mechanics based on FCI instrument indicated student in Junior level better than Sophomore and Freshman. The possibility reason was the level of course's material in Junior has been very much and already took a completely mechanics-course. *Second*, the overall level of misconception among college students on the subtopic of force and motion based on FCI instrument was moderate (68.86%). The highest levels of misconception are the subtopic of kinds of force with fluid contact (81.67%), Newton's second law (78.33%), kinds of force with solid contact (76.67%), and the superposition principle (75.56%). *Third*, college students have a very low understanding regarding the basic concepts of the kinds of acceleration, kinematics, energy conservation, superposition force, action-reaction, and free fall by using MBT. *Fourth*, the overall level of misconception among college students based on MBT instrument was high (75.91%). The highest levels of misconception were the topics of kinematics; both centripetal and average acceleration (86.67% and 85.56%, respectively). The other concepts in general principles (such as: energy conservation, superposition of force, free fall, action-reaction, and kinematics), students also performed high level in misconception.

**NOTES**

1. The paper was presented at the **31st** Annual **International Conference of Association of Science Education Taiwan (ASET)**, Howard Beach Resort - Kenting, Pingtung County, Taiwan, 10-12 December 2015.
2. Adopted to Indonesia case by Syuhendri, 2012.

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