Research Article doi: 10.12973/eu-jer.9.2.699

European Journal of Educational Research

Volume 9, Issue 2, 699 - 708.

ISSN: 2165-8714

http://www.eu-jer.com/

Developing MeMoRI on Newton's Laws: For Identifying Students' Mental Models

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Received: January 6, 2020 ▪ Revised: March 11, 2020 ▪ Accepted: March 26, 2020

Abstract: The identification of students' mental models is crucial in understanding their knowledge of scientific concepts. This research aimed to develop a Mental Models Representation Instrument on Newton's Laws (MeMoRI-NL). The ADDIE (Analyzing, Designing, Developing, Implementing and Evaluating) model was used as a research method. The sample consisted of 30 students of 15-16 years-old at one of senior high school in Tatar Pasundan. The data was examined using Rasch analysis on validity, reliability, level of difficulty, and distributions of students' mental models. Students' mental models were classified as Scientific (SC), Synthetic (SY), Synthetic almost Misconception (SYM), and Initial (IN) model. Based on the evaluating stage, students' mental models are mostly in the SYM and IN model. Consequently, it can be concluded that the Mental Models Representation Instrument on Newton's Laws (MeMoRI-NL) can be developed using the ADDIE model and most of the students' mental model has not been following scientific knowledge. Based on this research, teachers or educators should enhance students' mental models, especially for female students.

Keywords: *MeMoRI-NL, mental models instrument, Newton's laws, students' mental models.*

To cite this article: Fratiwi, N. J., Samsudin, A., Ramalis, T. R., Saregar, A., Diani, R., Irwandani, I., Rasmitadila, & Ravanis, K. (2020). Developing MeMoRI on Newton's laws: for identifying students' mental models. *European Journal of Educational Research, 9*(2), 699-708. https://doi.org/10.12973/eu-jer.9.2.699

Introduction

Students' previous knowledge involves not only formal knowledge learned at school but also social and observed information (Docktor & Mestre, 2014; Ozcan & Bezen, 2016; Urey, 2018). Previous knowledge shows a significant part of learning information. Students' previous knowledge that is not in line with scientific concepts (known as misconceptions or alternative conceptions) is a major problem in learning (Buber & Coban, 2017; Costu et al., 2010; Irwansyah et al., 2018; Kurniawan et al., 2019; Latifah et al., 2019; Maharani et al., 2019; Samsudin et al., 2017; Tortop, 2012). Students must have a conceptual understanding because this is the most rudimentary thing in learning physics (Putranta & Supahar, 2019). Conceptual understanding has a significant and deliberate site in the learning activities (Lestari et al., 2019; Yuberti et al., 2019) because it is not only to rebuild the sense of relations but also to develop the integration of information that has been formerly possessed. Students' problems usually occur from the delinquent of mental models created in their connections to the world (Joness et al., 2011; Moutinho et al, 2016; Ozcan, 2013). In other words, the mental model based on the students' previous knowledge is supposed to gracefully trust theory and practice (Stains & Sevian, 2015). Students' mental models are shaped when they absorb novel ideas and make influences concerning information acknowledged (Amalia et al., 2018; Wang & Barrow, 2011). Mental models direct the internal representations that students arrange in the facility to seem sensible of concepts (Kurnaz & Eksi, 2015; Ozcan, 2013; Ozcan & Bezen, 2016; Stains & Sevian, 2015). Mental models are a very beneficial paradigm in their thoughts(Didis et al., 2014). Mental models support us to comprehend the construction of matters. Students practice a mental model to describe, distinguish, and comprehend actual world conducts and constructions (Kurnaz & Eksi, 2015).

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Mental models have some characteristics, they are exceptional to individually distinct, incomplete, unstable, unscientific, ungenerous, and do not have stable borders (Didis et al., 2014; Greca & Moreira, 2000; Jones et al., 2011; Moutinho et al., 2016). Accordingly, mental models are significant to be recognized because it produces a crucial part in student learning as they riddle the information they attend to and absorb and it is imperative to understand the knowledge structure process because they reflect and represent the outside realm which is advanced through the individual cognizance (Moutinho et al., 2016; Rook, 2013). They are private and scientifically unpredictable, even though they are enormously valuable and practical for students to solve problematic conditions being reflected as their prior knowledge (Coll, France, & Taylor, 2005; Moutinho et al., 2016). Furthermore, mental models could assist them to distinguish and understand a concept and to identify faults in their understanding (Stains & Sevian, 2015). Through the students' mental models, a misconception or alternative concept is identified (Amalia et al., 2018). Students' mental models may be exposed to the source of terms and arrangements that reflect perceptions about an assumed concept.

A mental model is multifaceted and diverse. Their categorization involves the assembly of rich information from participants through interviews (Coll & Treagust, 2001; Stains & Sevian, 2015), paper-and-pencil forms (Ozcan, 2015), open-ended (Kurnaz & Eksi, 2015), or diagnostic tests (Moutinho et al., 2016). Since mental models are closely related to conceptual understanding, mental models can be identified through a diagnostic test such as a two-tier test Moutinho et al. (2016). A two-tier test involves the concept and students should categorize the sentences into true, false or don't know. The second tier had some sentences transcribed in a multiple-choice that defend the responses of the first tier. The studies of two-tier tests to identify mental models have not been done frequently because these tests are usually used to identify misconceptions. Two-tier test that is usually used to identify students' misconceptions consist of the conventional multiple-choice question at the first tier and its reason at the second tier. Thus, this form can also be used to identify students' mental models.

The identification of students' mental models is significant for being able to understand their knowledge of scientific concepts (Didis et al., 2014). Many students have difficulty in understanding basic physics concepts such as force, acceleration, movement, gravitational acceleration, and so on (Kaniawati et al., 2019; Liu & Fang, 2016; Saglam-Arslan & Devecioglu, 2010). These concepts are stated as abstract concepts that are problematic to be absorbed by students (Ozcan & Bezen, 2016). It is emphasized that students have not erudite the most rudimentary Newtonian concepts (Fratiwi et al., 2018). Newton's laws are imperative because they have effortlessly observable submissions in the everyday subsists of students (Ozcan & Bezen, 2016; Saglam-Arslan & Devecioglu, 2010). The common research about Newton's laws is intended to identify students' misconceptions or alternative conceptions midst primary, secondary, university students, pre-service teachers, and teachers (Saglam-Arslan & Devecioglu, 2010). Fascinatingly, there has been an inadequate quantity of research about mental models related to students' conceptions. Accordingly, researches on mental models have become progressively significant.

Research about mental models on Newton's Laws usually focuses on Newton's Second Laws et al. (2004) investigate students' mental models on Newton's Second Laws and classify them into Newtonian, Aristotelian, and hybrid models. Furthermore, Ozcan and Bezen (2016) discuss mental models on the concepts of force and velocity into Newtonian, Aristotelian, and Impulsive models, specifically for Newton's Second Law. This study also classifies that pre-service teachers have three mental models; accurate, incorrect, inadequate, and inconsistent knowledge. Students' mental models on the three Newton's laws are still rarely examined. Kurnaz and Eksi (2015) classify students' mental models as Scientific (SC), Synthetic (SY), and Initial (IN) model for friction force. These mental models are classified based on students' conceptions. Thus, we proposed to the arrangement of students' mental models on Newton's Laws as Kurnaz & Eksi classification (2015) with a slight difference in the Synthetic model. The SY model is separated into two models, they are Synthetic (SY) and Synthetic almost Misconceptions (SYM) model. Students are classified as the SYM model if half of their answers are in the misconception category.

Students' mental models were gathered using the diagnostic test in the form of two-tier test named MeMoRI-NL (Mental Model Representation Instrument on Newton's Laws). This instrument can be examined through Rasch analysis. The Rasch analysis attributed to Danish mathematician Rasch (1960) to sustenance accurate measurement. Rasch measurement has been practical in a diversity of conducts in education, school psychology, and numerous other areas (Boone & Noltemeyer, 2017). It has been practiced, developed, evaluated, and expanded through surveys and tests (Boone & Noltemeyer, 2017). In physics education, Rasch analysis has been done in numerous studies, but analysis for multi-tier instruments is still infrequently initiated (Aminudin et al., 2019). Therefore, this study aimed to develop a Mental Models Representation Instrument (MeMoRI) on Newton's Laws via Rasch analysis. The instrument is used to identify students' mental models. By knowing mental models, it can be known students' conceptual understanding.

Method

Participants

Participants in this research are 30 K-11 students (10 males and 20 females, their ages among 15-16 years-old). All the participants have been learned about Newton's Laws when they are in K-10. Participants were selected by cluster sampling technique, explicitly random sample selection because the population is divided into groups (Taherdoost, 2016). In this study, the population consisted of five groups, and then one group was randomly selected. The research was done at one of senior high school in *Tatar Pasundan* (Sukabumi) which is about 98 km from the capital of West Java (Bandung).

Research Design

The ADDIE (Analyzing, Designing, Developing, Implementing and Evaluating) model was used as a research method (Hess & Greer, 2016; Samsudin, et al., 2016; Widyastuti & Susiana, 2019) as displayed in Figure 1.

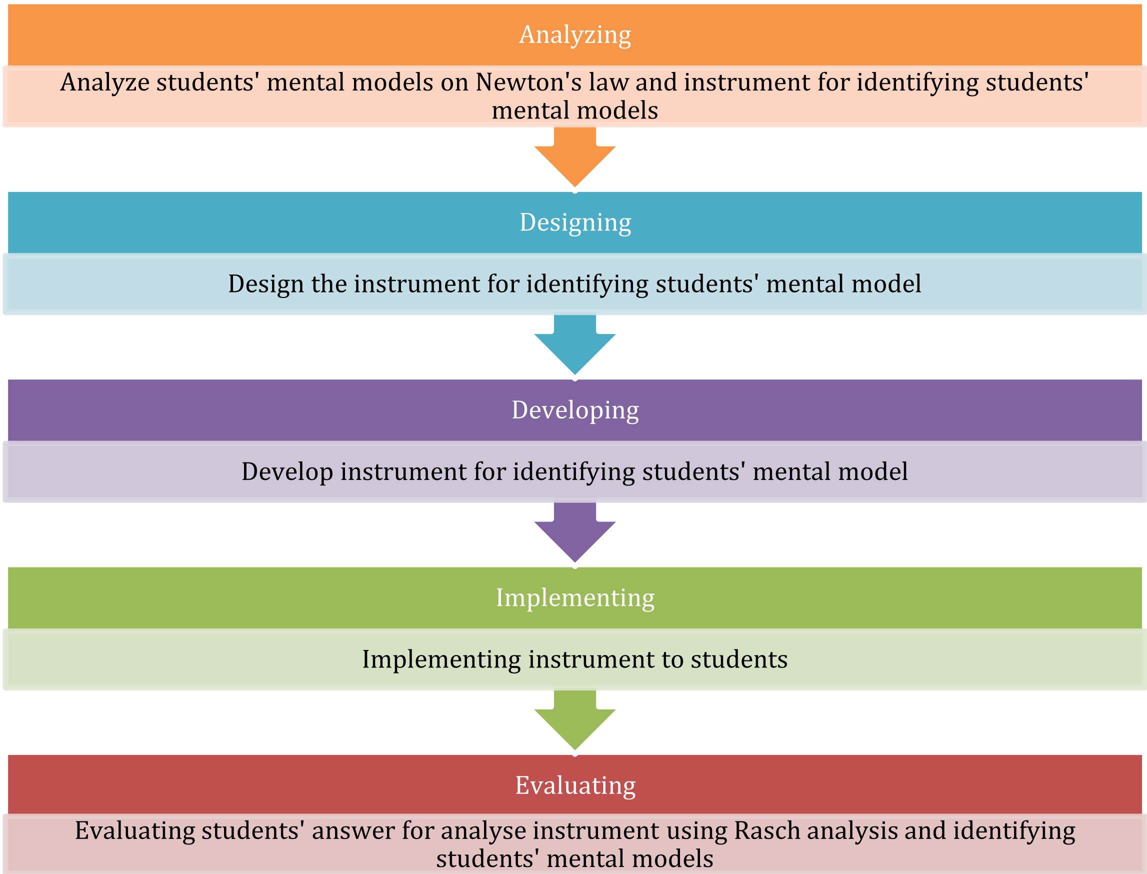

Figure 1. Research design through the ADDIE model

Data Analysis

Data analysis consisted of three phases on the evaluating stage. The first phase was the analysis of students' conceptions based on criteria in Table 1 as Sound Understanding (SU), Partial Understanding (PU), Error (ER), Misconception (MC), and No Coding (NC). The second phase was scoring the students' conceptions. This score used for analyzing validity (uni-dimensionality), reliability (item reliability) and level of difficulty (variable map) on Winstep 4.4.5 software. The scoring is shown in Table 1.

Table 1. Categories of students' conceptions (Kaltakci & Didis, 2007)

Conceptions Categories	Tier-1	Tier-2	Score
Sound Understanding (SU)	Correct	Correct	3
Partial Understanding (PU)	Correct	Wrong	2
Error (ER)	Wrong	Correct	1
Misconception (MC)	Wrong	Wrong	0
No Coding (NC)	No answer at one or all tier		-

The last phase was the analysis of students' mental models based on students' conceptions as Scientific (SC), Synthetic (SY), Synthetic almost Misconception (SYM), and Initial (IN). The criteria are shown in Table 2.

Table 2. Categories of students' mental models (Kurnaz & Eksi, 2015)

Mental Models Categories	Conceptions Categories
Scientific (SC)	Conceptions for four questions at SU, PU, or combination SU and PU
Synthetic (SY)	Conceptions for four questions at combination SU, PU, ER, MC, and NC, but MC no more than one question.
Synthetic almost Misconception (SYM)	Conceptions for four questions at combination SU, PU, ER, MC, and NC, with MC is more than one question.
Initial (IN)	Conceptions for four questions at ER, MC, NC, or combination ER, MC, and NC

Findings

The findings section will be presented according to the ADDIE model as follows.

Analyzing

At the analyzing stage, we analyzed the students' mental models and their identification. The identification of students' mental models mostly used interviews and open-ended questions (Coll & Treagust, 2001; Kurnaz & Eksi, 2015; Stains & Sevian, 2015). Mostly, the result of interviews and open-ended questions were analyzed qualitatively. Thus, we used diagnostic test in form of two-tier test to identify students' mental models through Rasch analysis.

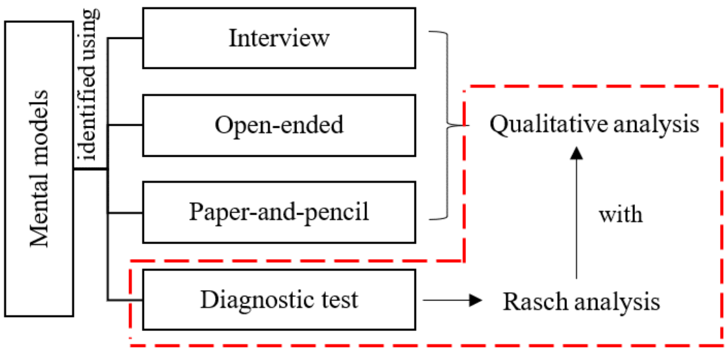

Figure 2. The Result of Analysis Stage

Designing

At the designing stage, the MeMoRI-NL was designed in the form of a two-tier test as shown in Figure 3.

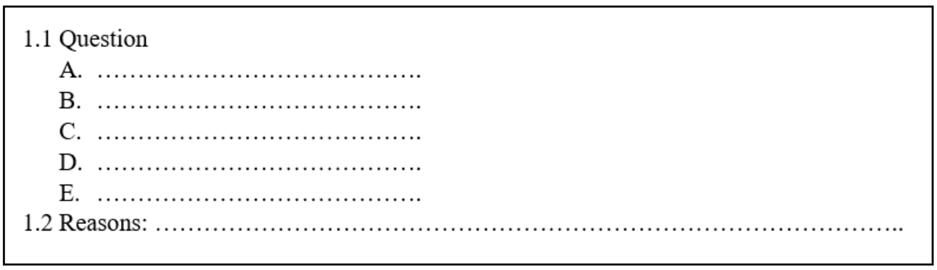

Figure 3. Design of MeMoRI-NL

Developing

At the developing stage, we develop MeMoRI-NL based on the design. The questions were chosen from the original Force Concept Inventory, three questions about Newton's First Law, three questions about Newton's Second Law, three questions about Newton's Third Law, and three questions about the type of forces. The indicators are shown in Table 3.

Table 3. The indicators of questions on MEMORI-NL

Concepts	Indicators
Inertia	Students can explain the velocity of objects on the track without friction
	Students can deduce the trajectory of objects based on the nature of inertia
Force balance	Students can explain the force balance acting on a regular straight motion
Effect of force on acceleration	Students can deduce the effect of force on the acceleration of objects
Effect of force on speed	Students can explain the effect of momentary forces on the speed of objects
Action-reaction force	Students can explain the action-reaction force on two colliding objects
	Students can explain the action-reaction force in the event of an impulse
	Students can explain the action-reaction force on a stationary object
Gravity	Students can compare the influence of gravity on time
Gravity and normal force	Students can classify the force of gravity and the normal force

After that, we developed the instrument. The example of MeMoRI-NL is shown in Figure 4.

1.1 Two metal balls of the same size but one ball weigh twice as big as another ball. Both balls are dropped from the roof of the building at the same time. The time it takes for the two balls to reach the ground is ...

A. about a half times longer for heavier balls
B. about a half times longer for lighter balls
C. is relatively the same for both balls
D. relatively longer for heavier balls, but not half the time
E. relatively longer for lighter balls, but not half the time

1.2 Reasons: ....

Figure 4. The example of MeMoRI-NL

Implementing

At the implementing stage, MeMoRI-NL was distributed to 30 students. Students' answers were analyzed through the category of conceptions and mental models as described in the result bellow.

Evaluating

Before identifying students' mental models, MeMoRI-NL was analyzed using Rasch analysis for its validity, reliability, and level of difficulty.

Table 4. Result of the validity of MeMoRI-NL

```
INPUT: 30 Person  12 Item  REPORTED: 30 Person  12 Item  4 CATS   WINSTEPS 4.4.5
--------------------------------------------------------------------------------

     Table of STANDARDIZED RESIDUAL variance in Eigenvalue units = Item information units
                                          Eigenvalue   Observed   Expected
Total raw variance in observations     =     18.2625 100.0%         100.0%
  Raw variance explained by measures   =      6.2625  34.3%          32.8%
    Raw variance explained by persons  =       .2873   1.6%           1.5%
    Raw Variance explained by items    =      5.9752  32.7%          31.3%
  Raw unexplained variance (total)     =     12.0000  65.7% 100.0%   67.2%
    Unexplned variance in 1st contrast =      2.0915  11.5%  17.4%
    Unexplned variance in 2nd contrast =      1.8400  10.1%  15.3%
    Unexplned variance in 3rd contrast =      1.5266   8.4%  12.7%
    Unexplned variance in 4th contrast =      1.2333   6.8%  10.3%
    Unexplned variance in 5th contrast =      1.1024   6.0%   9.2%
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In Table 4, the index of raw variance explained by measures was 34.3%. This index was more than 20%. So, MeMoRI-NL had fulfilled validity measurements. The result of the reliability of MeMoRI-NL is shown in Table 5.

Table 5. The result of the reliability of MeMoRI-NL

SUMMARY OF 12 MEASURED (NON-EXTREME) Item

	TOTAL SCORE	COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD
MEAN	10.6	29.8	.00	.32	.99	.10	1.06	.21
SEM	3.6	.1	.18	.03	.06	.14	.16	.22
P.SD	11.9	.4	.58	.11	.21	.46	.52	.72
S.SD	12.4	.4	.61	.12	.22	.48	.54	.76
MAX.	48.0	30.0	.77	.53	1.30	.69	2.14	1.63
MIN.	2.0	29.0	-1.53	.18	.43	-.96	.29	-.67

REAL RMSE .35 TRUE SD .47 SEPARATION 1.34 Item RELIABILITY .64
MODEL RMSE .34 TRUE SD .48 SEPARATION 1.42 Item RELIABILITY .67
S.E. OF Item MEAN = .18

Item RAW SCORE-TO-MEASURE CORRELATION = -.93
Global statistics: please see Table 44.
UMEAN=.0000 USCALE=1.0000

Table 5 shows the value of item reliability .64 and .67, which the reliability for a MeMoRI-NL comprised in the sufficient category. The level of difficulty shown in Figure 5.

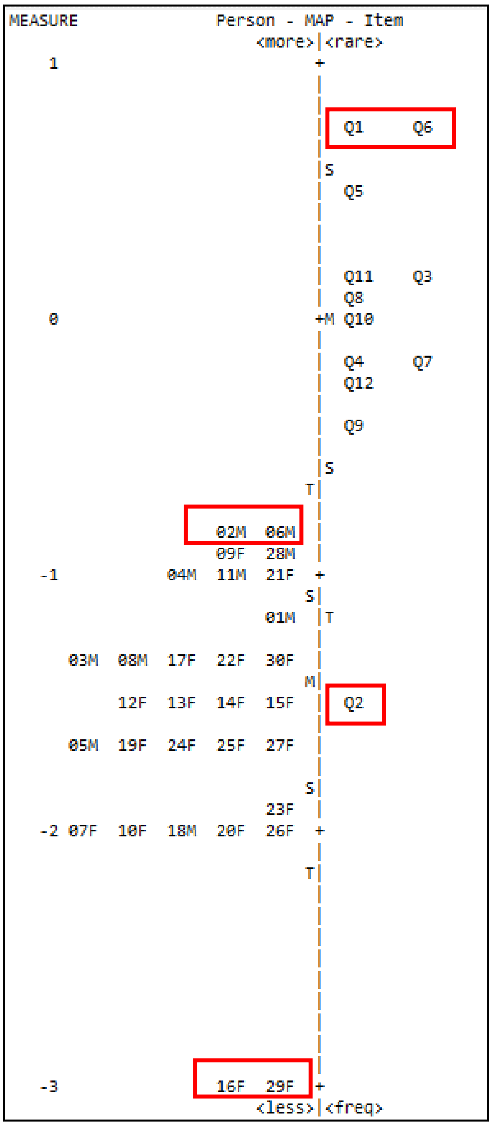

Figure 5. The result of the level of difficulty MeMoRI-NL

From Figure 5, the left part is the distribution of students and the right part is the distribution of questions. All of the students can't answer correctly for all questions except question number 2 (Q2). Students 12F, 13F, 14F, and 15F can't answer Q2. Question 2 (Q2) was the most convenient. Moreover, Q1 and Q6 were the most difficult question for students. Male student numbers 2 and 6 (02M and 06M) had the highest ability. Furthermore, female student numbers 16 and 29 (16F and 29F) had the lowest ability.

After analyzing the validity, reliability, and level of difficulty, we identified students' mental models. The percentages of students' mental models are shown in Figure 6.

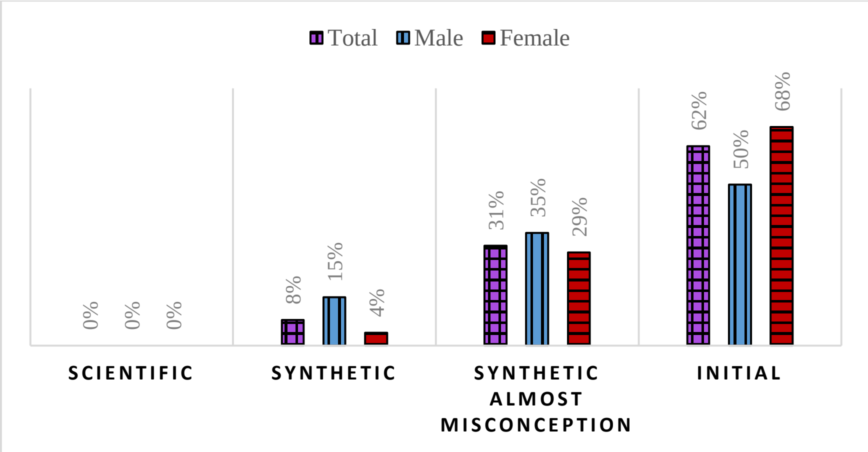

Figure 6. Percentages of Students' Mental Models on Newton's Laws

From Figure 5, there are no students who have a scientific mental model, both male and female students. There are 8% of students have a synthetic model with 15% male students and 4% female students. Then, 31% of students have a synthetic almost misconception model with 35% of male students and 29% of female students. Finally, 62% of students have an initial model with 50% of male students and 68% of female students. This indicates that male students have the most mental models in synthetic and synthetic almost misconception models while female students have the most mental models in the initial model. The example of students' mental models for synthetic, synthetic almost misconception, and the initial model is shown in Table 6.

Table 6. The Example of Students' Mental Models

Mental Models Categories	Example of Students' Mental Models
Synthetic (SY)	In Newton's First Law, 02M can choose the rocket's trajectory after the rocket is at equilibrium i.e. the rocket will continue to move by its original direction of movement (Q9). 02M can also answer that the rocket velocity at that time was constant, but he could not state the reason (Q10). However, 02M states that the velocity of the ball moving on the track without friction will continue to decrease because over time the ball will stop (Q3). The 02M conception for Q9 and Q10 are Partial Understanding (PU) while Q3 is in the Misconception (MC). So, 02M has an SY mental model.
Synthetic almost Misconception (SYM)	In Newton's Second Law, 09M can answer Q2 that the speed of the ball immediately after receiving a kick is greater than the initial speed or final speed, but 09M cannot reveal the reason that the ball gets accelerated due to the force. Then, 09M cannot choose the rocket trajectory after the rocket engine is started (gets constant force) in Q7. Also, 09M cannot determine the speed of the rocket when the rocket engine is started in Q8. 09M has Partial Understanding (PU) for Q2 and Misconception (MC) in Q7 and Q8. Therefore, 09M has an SYM mental model.
Initial (IN)	In Newton's Third Law, 23F answer that when a collision between a truck and a small car, the truck will give a greater force to the car because of the truck have greater mass (Q1). The 23F also answer that when the car pushed the truck to move at a constant speed, the car and truck did not exert force on each other. The truck is pushed forward because it is in the direction of the car's impulse. 23F gives the reason that trucks have a greater mass than the car (Q12). For Q5, 23F answered that when a student pushes the other students, two students give force to each other but students who have a greater mass will give a greater force. 23F gives the reason that the action-reaction force is always there as long as objects interact. The 23F conception for Q1 and Q12 is Misconception (MC) while for Q5 is Error (ER). So 23F has an IN mental model.

Discussion and Conclusion

Mental models need to be identified early on because they can influence the learning process. The identification of students' mental models is significant for being able to understand their knowledge of scientific concepts (Didis et al., 2014). Students may have diverse experiences and views about concepts linked to science in their situation and may start their education with the attainments they have (Urey, 2018). Also, teachers must design learning processes that are following students' mental models, both learning models, approaches or strategies, instructional media, and textbooks. The students' mental models in Newton's Law need to be identified to make it easier for students to learn further physics concepts. This is because concepts such as acceleration, force, mass, etc. are basic concepts in physics. Furthermore, the phenomenon of Newton's Law is also often found by students in everyday life.

Based on this research, we have been developing an instrument that can be used to identify students' mental models named Mental Model Representation Instrument on Newton's Laws (MeMoRI-NL). The MeMoRI-NL was developed through the ADDIE (Analyzing, Designing, Developing, Implementing and Evaluating) model. From Rasch analysis, MeMoRI-NL had a fulfilled criterion of validity and sufficient category of reliability. Thus, MeMoRI-NL was valid and reliable to use. Figure 4 described that all students could not answer correctly 11 questions of MeMoRI-NL. This caused the percentage of students' mental models on the SC model is 0%. Students cannot answer the questions correctly because the learning process in the class emphasizes less on concepts but the using formulas (Fratiwi, Utari, & Samsudin, 2019). Students maintenance about formulas that implicate concepts (Sağlam-Arslan & Kurnaz, 2009). Moreover, physics teachers inclined to focus on concerning formulas and did slight to promote the advancement of student understanding of the related concepts (Ebersbach et al., 2011; Mulhall & Gunstone, 2012).

When viewed from Figure 4, the students who have the highest ability are 02M and 06 M (male students), while the students who have the lowest ability are 16F and 29F (female students). The 02M students have the SY mental model for Newton's First Law and Newton's Second Law, and the IN model for Newton's Third Law and types of force. The 06M students have the SYM mental model for Newton's First Law and Newton's Second Law, the SY model for Newton's Third Law, and the IN model for types of force. Whereas 16F and 29F students have IN mental models for all sub material of Newton's Law and all of which are in the MC category. This also supports the finding that the mental model of female students is low for the SY and SYM models, and high for the IN mental model. This is because male students have more concepts grounded on measures that happen while female students have more theoretic concepts (Sagala et al., 2019). Male students rational through concepts, logical, and knowledgeable thinking forms are talented to see the reality of consistent data properly, intelligent to achieve investigation through a method, and attraction a decision to offer responses to complications grounded on evidence, concepts, and theory. Although female students have unvarying and detailed forms of thinking, comparable to solve problems increasingly and deliver comprehensive measures assumed through others to discover novel concepts in learning (Saputra et al., 2019).

In conclusion, MeMoRI-NL can be developed through the ADDIE model. This instrument can be analyzed using the Rasch analysis for validity, reliability and level of difficulty. MeMoRI-NL was valid and reliable to use to identifying students' mental models on Newton's Laws. Moreover, most students' mental models are in the IN model, so students' mental model has not been following scientific knowledge.

Recommendations

Based on the results obtained, the students' mental models are still in the synthetic and initial model. However, because of the importance of the students' mental models in the learning process, the mental models need to be improved to be a scientific model. Thus, teachers or educators must detect students' mental models before the learning process and use the correct approach to enhancing students' mental models, like the POE strategy. Through the POE strategy, students can predict, observe and explain the results of predictions and observations. If there is a difference between predictions and observations, students' beliefs will be "shaken" so that they can change the wrong mental model. This research was only conducted on a small sample in Sukabumi, West Java. By using the Winstep software, the sample used could reach 75 participants. Therefore, further research can develop instruments in other areas with more samples.

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