Identifying K-10 Students’ Learning Difficulties on Learning Kepler’s Law using Worksheet: Is It Worth?

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Abstract. This study set out to identify K-10 students’ learning difficult when they learn about Kepler’s Law. The research method utilized in this study was the single-intrinsic case study. The subject of this study was 19 students of one of a private school in Cianjur, Indonesia that consist of 12 females and 7 males from people with a background were mostly merchant. Students’ worksheet was used to identify students’ learning obstacles. Through the qualitative analysis of student answers to student worksheets, it can be found that students’ learning difficulties when learning Kepler Laws in the form: 1) understand the physical meaning of First Kepler's law, 2) identify and discover the relationship of physical quantities that work planets when interacting with the sun, 3) perform mathematical operations to derivate the Kepler's third law equation and apply it in some cases. Through this analysis, we can identify K-10 grade students’ learning difficulties when learning Kepler's Laws.

1. Introduction

Learning difficulties is one of the things that often occurs in learning and must be resolved by the teacher in learning physics. Numerous factors that cause students learning difficulties in class when they learn physics, for example, students were lack to apply mathematical process in physics [1]. Students who did not have enough mathematical ability, will certainly have weak physical ability [2]. Students’ difficulties in learning physics are related to their mathematical ability that has not been sufficient for associating the mathematical concepts to physics knowledge, mathematical concept as the basis of physics should be taught first [1].

There were few ways to identify students’ learning difficult. Smith, et.al [3] was conducted the research to investigate K-10 students’ learning difficult on thermodynamics topics by using two different questions, one as an ungraded survey in class and one as a homework problem then categorized students’ response by specific answer. Savall-Alemany, et.al. [4] was utilized questionnaire on quantum topics to identify students’ learning difficult. Lopez and Pinto [5] did the research in order to identify student learning difficult on the friction-heating at the microscopic level and the electromagnetic induction through the classification of identified students’ answers from the point of view of which difficulties can be involved. As described previously, students’ difficulties can come from the topics that contain mathematical equations in them. Mathematic is used to solve problems in physics from elementary to high school and a tool for developing theory in physics [6]. In Indonesian physics-course syllabus on K-10 students, there were so many topics that students must learn, one of them is Kepler’s Law topic. Physics-course study the natural phenomena related to daily life [7],

[1] Smith, et.al [3], [2] Smith, et.al [3], [3] Savall-Alemany, et.al. [4], [4] Lopez and Pinto [5], [5] Lopez and Pinto [5], [6] Smith, et.al [3], [7] Smith, et.al [3].
involving the Kepler’s Law which considers the regularity of motion of celestial bodies such as planets, asteroids, and comets.

Study on astronomy education, students’ understanding levels, misconceptions, and difficulties about basic astronomy topics have been explored in several [7-16]. Liliawati, et.al. [17] found that, for example, topic on the motion of celestial bodies was elusive because students had difficulty in imagining their motion on the sky. On the other hand, Yu, Sahami and Denn [18] state that ideas about the actual shape of orbital trajectories and details of the velocities of objects in motion have not been studied to a great extent. In brief, Kepler’s Law topics on Indonesian syllabus contain four main concepts, there were Newton force gravity, also first, second and third Kepler’s law. First Kepler’s law states the orbital shape of the planet, planets orbit the Sun in elliptical orbits, with the Sun at one of the foci of the ellipse [18,19]. Second Kepler’s law express the consequences of the planet's orbital shape, the planets sweep out an equal area in equal amounts of time as they travel in their elliptical orbits [18, 19]. Figure 1. illustrate the elliptical orbit of mercury, same colour shows the same area.

![Figure 1. The illustration of Mercury Elliptical orbit, with the equal area. The illustration was from University of Nebraska-Lincoln](image)

As illustrated in Figure 1, Noll [19] states that the angular momentum (L) of a particle that have mass (m), moving with a velocity (v) at a perpendicular position (r⊥) to the line of the velocity is defined as

$$L = mrv_{\perp}$$  \hspace{1cm} (1)

While third Kepler’s law state the square of the period of any planets is proportional to the cube of the semimajor axis of the ellipse [18, 19], or it can be expressed by the equation

$$\frac{T_1^2}{T_2^2} = \frac{a_1^3}{a_2^3}$$  \hspace{1cm} (2)

Although there have been many studies on the study of Kepler's law, it is rare to examine students' understanding of the relationship between the concepts that students have learned in the topic of circular motion and the movement of planets in Kepler's law. In this study, we develop student worksheet based on Blooms' taxonomy on Kepler’s Law Concept to identify students’ learning difficult. Worksheet used because we want to accommodate the student to track the learning process. Research framework is illustrated in the following chart.
2. Method

2.1 Research Design

Our main aim was to identify students' learning difficult when they learn Kepler's Law use worksheet-answer then we spell out their learning difficulties. Based on this we utilize a qualitative approach. The qualitative research approach utilized is a case study. The type of case study used is a single intrinsic case study. Intrinsic case studies are often used in exploratory research when researchers search for information about some unknown phenomena by studying them in-depth [20]. We analyse students’ answer from the question in the worksheet, then we can identify the students' learning obstacles when they learn about Kepler’s Law.

2.2 Participants

The participants of this study were 19 students of K-10 grade on private school that consist of 12 females and 7 males from Karangtengah sub-district, Cianjur, Indonesia. Karangtengah was one of the sub-districts in the district of Cianjur with the fifth largest area of rice fields from 32 existing sub-districts. The average of students’ age were 15-16 years old. Generally, students’ parent was entrepreneur such as merchants. They were taking physics class for 135 minutes in a week.

2.3 Development of Students’ Worksheet

The instrument utilized in this study was in the form of questions presented in student worksheets. Each question presented in the worksheet represents the learning objective that refers to Bloom's thinking taxonomy. The types of questions that designed on the worksheet are continuous questions that refer to the stages of Bloom's thinking, for example, question number 1 asks students to think at the C1 level (remembering), then question number 2 asks students to think at the C2 level (understanding), and so on. In essence, every question on the worksheet is related to one another. The learning media and worksheet on Kepler’s Law learning was developed in Physics-Learning assessment course. It was discussed in class-discussion for 2 months (once meeting in a week) and received advice from assessment-expert lecturers and 12 students who had taught at several schools for several years in many provinces in Indonesia such as Sumatra and West Java. In addition, the worksheets that were developed were also reviewed by two astronomy education-expert and then obtained suggestion and then rectified. With the purpose of visualize the motion of the planet in their elliptical orbit, we utilized some animation and simulation such as pHet. In the direction to provide an overview of question in the worksheet, here the example for the question in the Kepler’s Law students’ worksheet on number 3, 4, and 5.
Table 1. The Example of Learning Objectives (LO) with Bloom’s Taxonomy and the Question on Worksheet

| Bloom Taxonomy (Question Number) | Learning Objective | Question on Worksheet |
|----------------------------------|--------------------|-----------------------|
| C3(3)                            | Determine the quantities of physics that work on planets around the sun | Based on 1st Kepler's law, draw the Earth's orbit against the sun along with the physical quantities that represent the motion of planets around the sun! |
| C4 (4)                           | Analyse the relationship of gravitational force with the velocity of the earth around the sun in the case of elliptical orbit trajectory according to Kepler's Second law | How does the magnitude of the gravitational force affect the velocity of the planet when it circles around the sun? The momentum of the planet's angle when around the sun is fixed value. In the same time span, the lines connecting planets to the sun sweep over the same area. Can you explain this? |
| C5 (5)                           | Evaluate the validity of Kepler's Second laws in the case of circular orbit trajectories (small eccentricity) | If it is assumed that the planet's orbit towards the sun is a perfect circle, what is the magnitude of the gravitational force and the velocity of the earth at each point in its orbit? Why can it happen? |

Subsequently developing process in assessment-course discussion, the worksheet was tested, through the results of the trial, the validity and reliability are verified. Each correct student answer is given a score of 1 and the incorrect student answer is given a score of zero, the validity and reliability of the worksheet are determined through the Rasch Analysis Model.

Validity of the Instrument
Test the validity based on item dimensionality by looking at the value of raw variance explained by measures. Express the data as follows:

Figure 3. Item Dimensionality Results
The value of raw variance by measures shows the percentage of 44.3% (> 40%), so that the validity of a categorized instrument is good [21].

Reliability of the Instrument

In addition to validity, a good instrument must also have good reliability. An instrument is said to be reliable when the results of testing the instrument get consistent results [22]. The following results of reliability testing using the Rasch analysis model is shown below.

![Figure 4. Item Reliability](image)

Item reliability shows the number 0.76 (> 0.7), which means the reliability of good tertiary instruments [22].

2.4 Learning Activity

After the learning material, including the worksheet, was prepared, the implementation of Kepler's legal learning was conducted in one meeting. The learning process lasts approximately 135 minutes. One week earlier, students had learned about Newton's law of gravity but had not used a structured worksheet like that used in learning the law of Kepler. The prerequisite concept is the concept of circular motion students have learned 4 months earlier. In order to visualize the movement of planets, a computer-based application, namely pHet, was used.

2.5 Data Analysis

As explained above that each question contained in the worksheet represents each of the 1 learning objective. If students can answer the questions correctly and meet the standards, then will be given a score of 1 and if students cannot answer correctly then will be given a score of zero.

3. Result and Discussion

Next students take part in the learning activities and fill in the worksheets, an examination of the students' answers on the worksheets is carried out. Each question on a worksheet represents a learning objective based on the stages of Bloom's thinking. The correct answer students were given a value of 1 and the incorrect answers were given a value of zero. The following results are the percentage of students' answers for each learning objective (LO). The percentage of each learning goal is analysed qualitatively.
LO1 has the highest achievement of 84%, meaning that 16 out of 19 students can achieve this LO. In the worksheet, students were asked to write down sounds from First Kepler's Law. Students can search for information through printed books, the internet, or remember that sound because when they were in secondary school, they have learned it. Because in the learning process students only write the sound of First Kepler's Law, almost all students can complete this question. Student’s right answer for the question on LO 1 are *all planets move in an elliptical path when circling the sun with the sun at one elliptical focus*. However, even though the answer to the LO1 question was very easy (just remembering), some students were still incorrect in answering. Student that coded by S11 and S15 answer the worksheet with the incorrect answer, their answer are *all the planets move in an elliptical path around the sun with the sun in one ellipse*. While, student that coded by S17 answer that the sound of First Kepler's Law is *all planets move in an elliptical path around the sun with the sun in either elliptical focus or a circle*.

Based on the findings, it can be identified that students have not understood the physical meaning of First Kepler's Law, so when writing the sound of Kepler's law, there are still found the students’ who answer incorrect. Students' understanding of reading results is one of the main assets in understanding science, especially physics. In line with Finneran [23] statement that students struggle with textbook reading and how this impacts their overall success in their science courses. This result was contrary to Givental [24] research report which states that the derivation of the first Kepler law was very difficult because it requires in-depth analysis. This happens because of the study of Givental, the point of view of the planet's orbit trajectory was conic. Meanwhile, in this study, Kepler's first law only mentions that the orbital path of the planet to the sun is elliptical. Furthermore, there were several notes for this research regarding Kepler's first law, this study has not yet discussed the ellipticity of planetary orbits. According to Yu, Sahami and Denn [18] results, most of the students thought that planets’ orbits are highly elliptical. Although Kepler’s first law states that the planets’ orbits are elliptical, they are not highly elliptical [16].

In LO3, students were asked to draw a planet's orbital path to the sun, then students are also asked to write down the quantities of physics that work on planets when circling the sun. Achievement of LO3 reached 84% because, at the beginning of the learning process, students were given re-explained topics about the physical concepts that they have been learned that used to understand Kepler's Law such as centripetal acceleration, circular motion and the magnitude of the force of gravity. The re-explained process was carried out because the concepts of centripetal acceleration, circular motion, and angular momentum were carried out because this concept had been studied before on different topics in physics curriculum and syllabus. Here the example of students’ answer on LO3.
Based on Figure 6 & 7, most of students can identify physical quantity of the planet that moves around the sun, complete with vector direction. Even so, there was also found that there were still students who experienced errors in describing the direction for each physical quantity. Student that coded by S7 and S14 did not write physical quantities that represent planetary motions, nor did they describe the direction of the vector. S20 wrote the right physical quantities but not draw the right direction of the vector of physical quantities. Based on Yu, Sahami and Denn [18] research, observed that 60% of the participants did not have any idea about the speeds of the planets, and some (20% of the participants) thought that planets move at constant speed.

Questions on number 6 (LO6) require students to use the physics quantities that were previously identified in the previous question to derive Kepler's third law equations. Most students find it difficult to substitute and carry out mathematical operations to solve this problem. Although the teacher was very dominant in directing students to solve the decline in equations, only 7% of students can complete the answers to these questions. This shows that students' mathematical abilities such as substituting equations and carrying out the displacement of segments are still very weak, so students cannot solve equations for Kepler's third laws. The student that can answer the question on LO6 were S6 and S9, their answer shown by Figure 8 and 9.

Because $G; M_{m}; 4\pi^2$ constant, it can write by C

$G: \text{gravity constant}$

$M_{m}: \text{Mass of sun}$

$M_{p}: \text{Mass of the planet}$

$r: \text{distance between sun and the planet}$
Niss [25] states that systematic-mathematics contained in the mathematical-analysis method prevents students from finding solutions to problems. So, it was found that students' mathematical abilities that are weak can become obstacles to learning in Kepler's Law which is loaded with mathematical analysis.

The most attainable learning objective achievement was shown by LO7. The question given to access LO was that students were asked to determine the mass of the planet Mars based on the known Mars orbit orbital period. Because the scoring made was 1 for answers that met the standard, and 0 for answers that did not meet the standard, while no students found the result of the mass of the planet Mars, the achievement for this learning objective was 0%. However, further analysis was carried out for this case, there were 12 students (63%) able to complete up to the example stage below in Figure 10 & 11, while 7 students (37%) could not make a mathematical step to be able to do the questions presented.

Known:

\[ T = 460 \text{ minutes} \]

\[ r = 9,4 \times 10^6 \]

\[ G = 6,67 \times 10^{-11} \]

Asked: \( M_m \) (Mass of Mars)

Solution:

\[ \frac{GM_m}{4\pi^2} = \frac{r^3}{T^2} \]

\[ M_m = \frac{r^3 4\pi^2}{T^2 G} = \frac{(9,4 \times 10^6)^3 4\pi^3}{(460)^2 6,67 \times 10^{-11}} = \]

In line with the expression of Niss [25] that several studies show that mathematical processes can cause students difficulty in understanding physics. On the other hand, Diba and Prabawanto [29] conducted the research to investigate students' ability of answering ratio and proportion problems, they found that roughly students utilize formula while they don’t understand why the formula be used in solving the concept of ratio and proportion as the one of the basic concepts in mathematics. In this case, there are still students who have difficulty performing variable transfer operations, students cannot change the general equation of Kepler's third law into an equation to determine the mass of the planet \( M = \frac{r^3 4\pi^2}{T^2 G} \). Most students also find it difficult to carry out multiplication operations and division of rank numbers, this is indicated by the absence of students who can find the result of the planet's mass in question. Mathematical competence of students will grow more optimal if the teachers are competent in managing the learning process [26]. In accordance with Safaah, Muslim, and Liliawati [28] that the teacher ought to decide the proper learning approach so that students' abilities cultivate optimally. The role of the teacher is extraordinarily deliberate in term of teaching and
learning process as they desire to take significance in presenting their responsibilities competently [30].

4. Conclusion

Based on the findings and discussion, it can be seen the percentage of student competency achievements for Kepler's Law Topics, with the percentage from the highest to the lowest of each learning objective obtainable in the student worksheet. As for this percentage, an analysis of the learning difficulties experienced by students. The learning barriers experienced by K-10 students' whey they were learning Kepler's law are students having difficulty: 1) understand the physical meaning of First Kepler's law, 2) identify and discover the relationship of physical quantities that work planets when interacting with the sun, 3) perform mathematical operations to derivate the Kepler’s third law equation and apply it in some cases.

Through this research, it was found several recommendations for further researchers to further study Kepler's law learning. Kepler's 3 law was closely related to students' mathematical abilities. Based on research findings, teachers should emphasize mathematical steps when deriving Kepler's 3 laws. This was important because through mathematical derivation, quantities of physics that works between planets and the sun can be explained in more depth.

References
[1] Retnawati H, Arlinwibowo J, Wulandari N F, Pradani R G 2018 Teachers's Difficulties and Strategies in Physics Teaching and Learning that Applying Mathematics, Journal of Baltic Science Education, 17 pp. 120-135
[2] Chiu M 2015 The Challenge of Learning Physics before Mathematics: a Case Study of Curriculum Change in Taiwan, Research in Science Education, 46, pp. 767-786
[3] Smith T I, Christensen W M, Mountcastle D B, Thompson J R 2015 Identifying Student Difficulties with Entropy, Heat Engines, and the Carnot Cycle, Physical Review Special Topics-Physics Education Research, 11 pp. 1-14
[4] Savall-Alemany F, Domenech-Blanco J L, Guisasola J, Martinez-Torregosa J 2016 Identifying student and teacher difficulties in interpreting atomic spectra using a quantum model of emission and absorption of radiation, Physical Review Physics Education Research, 12 pp. 1-16
[5] Lopez V and Pinto R 2017 Identifying secondary-school students’ difficulties when reading visual representations displayed in physics simulations, International Journal of Science Education, pp. 1-28
[6] Doran Y J 2017 The role of mathematics in physics: Building knowledge and describing the empirical world, ONOMAZEIN: Journal of Linguistic, philology and translation, pp. 209-226
[7] Mali G B and Howe A 1979 Development of earth and gravity concepts among Nepali children, Science Education, 5 pp. 685-691
[8] Nussbaum J 1979 Children’s conceptions of the earth as a cosmic body: A cross age study, Science Education, 1 pp. 83-93
[9] Sneider G and Pulos S 1983 Children’s cosmographies: Understanding the earth’s shape and gravity, Science Education, 2 pp. 205-221
[10] Baxter J 1989 Childrens’ understanding of familiar astronomical events, International Journal of Science Education, vol. 5, no. 11, pp. 502-513, 1989.
[11] Sadler P M 1992 The initial knowledge state of high school astronomy students, Harvard University
[12] Vasniadou S and Brewer W F 1992 Mental models of the earth: A study of conceptual change in childhood, Cognitive Psychology, 4 pp. 535-585
[13] Zeilik M, Bisard W and Lee C 2001 Research-based reformed astronomy: Will it travel?,” Astronomy Education Review, 1 p. 33
[14] Vasniadou S, Skopeliti I and Ikospentaki K 2004 Modes of knowing and ways of reasoning in elementary astronomy,” *Cognitive Development*, 2 pp. 203-222
[15] Ogan-Bekiroglu F 2007 Effects of model-based teaching on pre-service physics teachers’ conceptions of the moon, moon phases, and other lunar phenomena, *International Journal on Science Education*, 5 pp. 553-593
[16] Aktan D C and Dincer E O 2014 Examination of Pre-service Science Teachers' Understanding Levels of Kepler's Law with Ranking Task Question, *Journal of Baltic Science Education*, 2 pp. 276-288
[17] Liliawati W, Utama J A and Mursydhah L S 2017 The Concept Mastery in the Perspective of Gender of Junior High School Students on Eclipse Theme in Multiple Intelligences-based of Integrated Earth and Space Science Learning, *IOP Conference Series: Materials Science and Engineering*, pp. 1-5
[18] Yu K, Sahami K and Denn G 2010 Student Ideas about Kepler’s Laws and Planetary Orbital Motions, *Astronomy Education Review*, pp. 1-17
[19] Noll E D 2002 Teaching Kepler's Law as More than Empirical Statement, *Physics Education*, pp. 245-250
[20] Fraenkel J R, Wallen N E and Hyun H 2012 How to Design and Evaluate Research in Education, *New York: The McGraw-Hill Companies*
[21] Sumintono B and Widhiarso W 2014 Aplikasi Model Rasch untuk Penelitian Ilmu-Ilmu Sosial (edisi revisi), *Bandung: Trim Komunikata Publishing House*
[22] Sumintono B and Widhiarso W 2015 Aplikasi Pemodelan Rasch pada Assessment Pendidikan, *Bandung: Trim Komunikasi Publishing House*
[23] Finneran M L 2017 Improving Scientific Literacy through Reading Strategies: An Action Research Study, *Retrieved from https://scholarcommons.sc.edu/etd/4346*
[24] Givental A 2016 “Kepler's Law and Conic Section,” *Research Exposition: Springer*, pp. 139-148
[25] Niss M 2016 Obstacles Related to Structuring for Mathematization Encountered by Students when Solving Physics Problems, *International Journal of Science and Math Education*, pp. 1-22, 2016.
[26] Kurniawan D T, Suhandi A, Kaniawati I and Rusdiana D 2017 The Analysis of Learning Obstacle and Students Learning Motivation of Prospective Math Teachers in Basic Physics Class, *Journal of Physics: Conference Series*, pp. 1-9
[27] Saregar A, Irwandani I, Abdurrahman A, Parmin P, Septiana S, Diani R, & Sagala R 2018 Temperature and Heat Learning through SSCS Model with Scaffolding: Impact on Students' Critical Thinking Ability, *Journal for the Education of Gifted Young Scientists*, 3, pp. 39-54
[28] Safaah E S, Muslim M, Liliawati W 2017 Teaching Science Process Skills by Using the 5-Stage Learning Cycle in Junior High School, *IOP Conf. Series: Journal of Physics: Conf. Series*, 895, pp. 1-6
[29] Diba D M S, Prabawanto S 2019 The analysis of students’ answers in solving ratio and proportion problems, *IOP Conf. Series: Journal of Physics: Conf. Series*, 1157, pp. 1-6
[30] Masrifah M, Setiawan A, Sinaga P and Setiawan W 2019 The content quality of teacher’s pedagogical and professional competence standards of senior high school physics teacher guide books, *IOP Conf. Series: Journal of Physics: Conf. Series*, 1157, pp. 1-7